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THE ROLE AND USE OF FIRE IN SAGEBRUSH-GRASS AND PINYON-JUNIPER PLANT COMMUNITIES

A STATE-OF-THE-ART REVIEW

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FOREWORD

Fire management is a term often used to indicate a broadened perspective of the control and use of fire to meet land management objectives. Barney (1975) defined fire management as "the integrating of fire-related biological, ecological, physical, and technological information into land management to meet desired objectives." One of the most fruitful areas within which to practice these concepts is in that part of our wildlands used for range and wildlife purposes. This paper provides a knowledge base on the role and use of fire in sagebrush-grass and pinyon-juniper plant communities.

Sagebrush-grass and pinyon-juniper plant communities cover several hundred million acres of our western wildlands. The two communities provide the land base for much of the grazing and wildlife habitat in western North America and are increasingly important for recreational pursuits. The authors have drawn upon fire literature, unpublished information, and their own experience to provide this state-of-the-art summary of fire in these plant communities in direct response to the needs of land managers. The Fire in Multiple-Use Research, Development, and Application (RD&A) Program has been interested in preparing state-of-the-art summaries in many vegetative communities to facilitate the integration of fire into land management planning and has cooperated with the authors and their institutions in preparing this paper.

The Bureau of Land Management has been particularly interested in this document and has been helpful in providing the manager's viewpoint. James M. Linne, Bureau of Land Management Research Coordinator attached to the RD&A Program, has utilized this material in preparing prescribed burning guides for BLM field personnel. The findings and recommendations are currently being evaluated and implemented in the field. Thus the information is being utilized concurrently with publication.

The interest of BLM in the use of fire in sagebrush-grass and pinyon-juniper is understandable. Costs of fire suppression are increasing every year. Mechanical means of preparing seedbeds in these vegetation types is expensive. Spraying with herbicides is expensive as well as environmentally controversial. Fire can be used economically and yet be ecologically sound, although, intially, fire may need to be used in combination with other range improvement methods. Other agencies have similar concerns.

New and revised policies in fire management and land management planning call for more definitive answers, particularly in predicting consequences of management activities. This paper provides the basis for incorporating fire into sagebrush-grass and pinyon-juniper communities. It is the first of several state-of-the-art summaries that land managers need for planning the protection and use of fire in different vegetative types. I consider the effort put forth by the authors as a significant contribution to the management of sagebrush-grass and pinyon-juniper communities and to the fire literature.

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RESEARCH SUMMARY

Fire frequencies averaged 32 to 70 years in sagebrush-grass communities. Early spring and late fall fires are the least harmful to perennial grasses, although small plants and those with coarse stems are more tolerant of fire than large plants and those with leafy stems. Cheatgrass can be suppressed by burning in early summer, but the set-back is only temporary and perennials such as Idaho fescue and *Stipa* sp. are easily killed during this season of the year. Most forbs can easily tolerate fall burns, but not much data are available for early spring burns. The three subspecies of big sagebrush are easily suppressed by fire. They may or may not become re-established quickly after fire, depending on seed source. Antelope bitterbrush is very susceptible to fire, but some genotypes resprout if moisture is adequate following a burn. Rabbitbrush and horsebrush resprout vigorously after fire. All known data on the effects of fire on plants are summarized in this report.

Drought, competition, and fire played a complementary role in limiting the distribution of pinyon and juniper before grazing by domestic livestock became an influence. Natural fires occurred every 10 to 30 years, which kept the junipers restricted to shallow, rocky soils and rough topography. Heavy livestock grazing has reduced fuel for fires and has permitted pinyon and juniper to rapidly invade adjacent communities. Pinyon and juniper trees less than 1.2 m tall can easily be killed where there is adequate fine fuel to carry a fire, but dense stands of pinyon and juniper with bare soil may require an initial, expensive renovation procedure involving mechanical treatment, prescribed burning, and seeding. Thereafter, however, young pinyon and juniper trees can be kept out of the grassland or sagebrush-grass with a maintenance fire every 20 to 30 years. Mixtures of sagebrush and pinyon-juniper can be easily burned without fine fuel on the ground. Only alligator juniper is a sprouting species.

Effects of fire on grasses, forbs, and shrubs are covered in detail. Guidelines for conducting prescribed burns in sagebrush-grass and pinyon-juniper communities are presented. The guidelines should be used with the understanding that further research is needed to refine all prescriptions.

CONTENTS

SAGEBRUSH-GRASS COMMUNITIES

Distribution, Climate, Soils, and Vegetation

Sagebrush-grass vegetation covers at least 96.5 million acres (39.1 million hectares) in the Western United States (USDA Forest Service 1936), but probably considerably less than the 270 million acres (109 million hectares) estimated by Beetle in 1960 (Tisdale and others 1969). The largest contiguous area lies in eastern Oregon, southern Idaho, southwestern Wyoming, northern Utah, and northern Nevada (Vale 1975). Most of this area (fig. 1) occurs below the pinyon-juniper zone, but in the absence of a pinyon-juniper zone, sagebrush-grass vegetation will border curlleaf mahogany (*Cercocarpus ledifolius*), Gambel oak (*Quercus gambelii*), ponderosa pine (*Pinus ponderosa*) or Douglas-fir (*Pseudotsuga menziesii*). Sagebrush-grass communities also occur above the pinyon-juniper zone in the Great Basin (Billings 1951) and throughout most mountain plant communities in the Rocky Mountain and Intermountain regions (Beetle 1960).

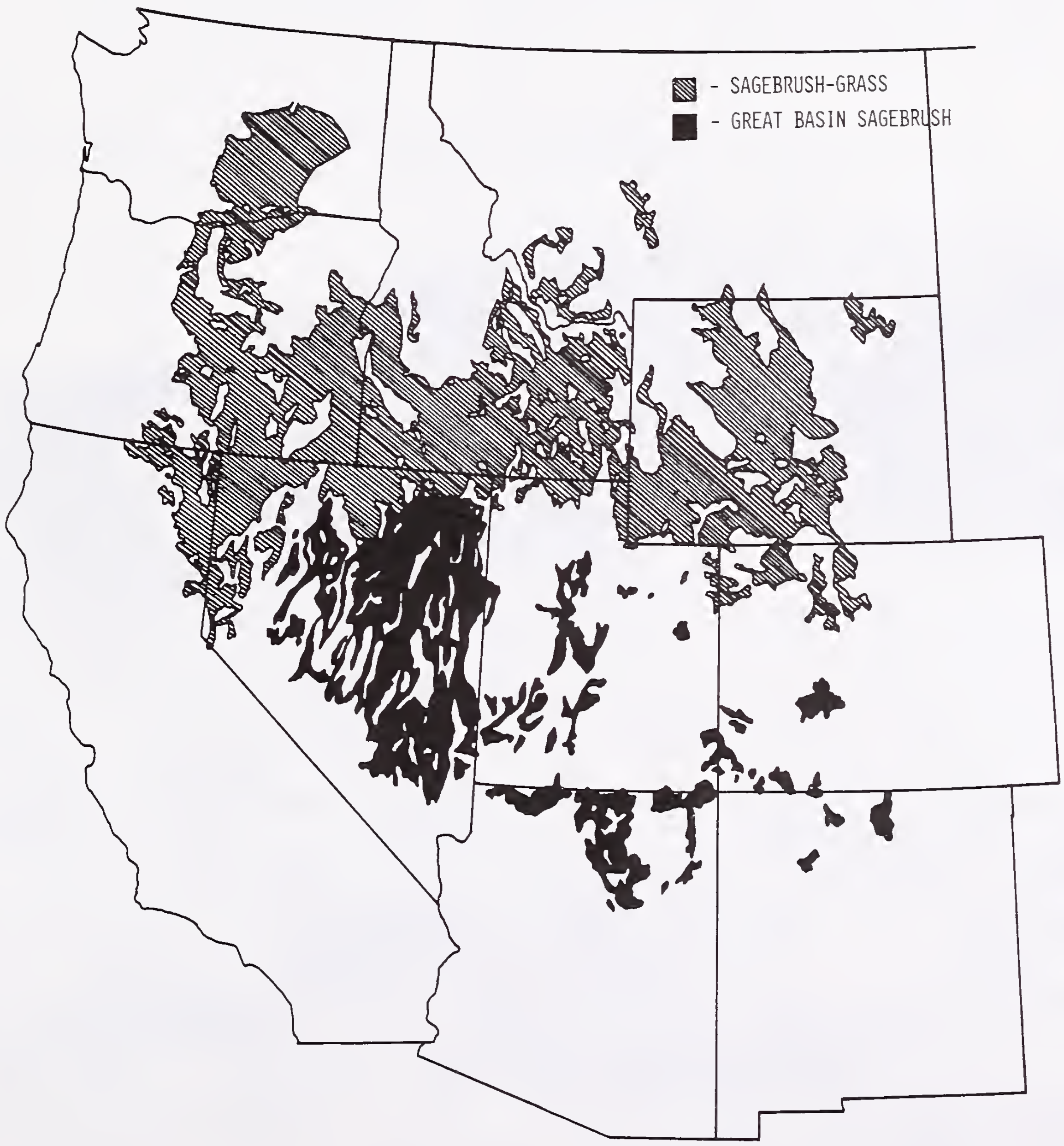

Figure 1.--Distribution of sagebrush and sagebrush-grass communities in the Western United States after Küchler (1964).

Most of the sagebrush-grass zone is found at elevations from 2,000 to 7,000 ft (610 to 2,134 m). The sagebrush-grass zone also occurs below 1,000 ft (305 m) in south central Washington and British Columbia and mixes with all vegetation zones to varying degrees up to 10,000 ft (3,049 m) (Beetle 1960), including the subalpine herbland. Where sagebrush-grass prevails below 7,000 ft (2,134 m), annual precipitation varies between 8 to 20 inches (20 to 50 cm) (Tisdale and others 1969). Soil texture varies from loamy sand to clay (Tisdale and others 1969). Most soils are derived from basalt, although extensive areas have soils derived from rhyolite (southeastern Oregon and Nevada), loess, lacustrine, alluvium, and limestone. Interactions of soils, precipitation, and elevation results in many distinct combinations of sagebrush-grass dominated ecosystems.

Three subspecies of big sagebrush--basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*), Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*), and mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*)--dominate the sagebrush-grass zone. Basin big sagebrush (3.28 to 16.41 ft; 1 to 5 m tall) and Wyoming big sagebrush (1.48 to 2.43 ft; 0.45 to 0.76 m tall) are the dominants from 2,001 to 7,002 ft (610 to 2,134 m), with the latter being the most drought tolerant (McArthur and others 1974). Basin big sagebrush occupies a 10- to 16-inch (25 to 40 cm) precipitation zone on deep, well-drained alluvial soils, whereas Wyoming big sagebrush occupies an 8- to 12-inch (20- to 30-cm) precipitation zone on shallow soils (Tisdale and others 1969). Mountain big sagebrush (2.43 to 4.00 ft; 0.76 to 1.22 m tall) is the most mesic subspecies and can be found at elevations from 5,000 to 10,000 ft (1,524 to 3,049 m) (McArthur and others 1974) where precipitation varies from 14 to 20 inches (35 to 50 cm) per year (fig. 2).

Figure 2.--Mountain big sagebrush in Idaho with an understory of Idaho fescue. (University of Idaho photo.)

Other species of sagebrush, in decreasing order of economic importance, are low sagebrush (*A. arbuscula*), three-tip sagebrush (*A. tripartita*), black sagebrush (*A. nova*), silver sagebrush (*A. cana* ssp. *viscidula* and *A. cana* ssp. *bolanderii*), alkali sagebrush (*A. longiloba*), Bigelow sagebrush (*A. bigelovii*), and scabland sagebrush (*A. rigida*) (Tisdale and others 1969; McArthur and others 1974). The first three species generally grow below 6,000 ft (1,830 m) elevation, although they can occur at higher elevations. Low sagebrush occurs on shallow soils or soils with a restrictive B horizon, largely in southern Idaho, Nevada, southeastern Oregon, and northeastern California (Fosberg and Hironaka 1964). Three-tip sagebrush occurs east of this region on mesic or dry soils in a precipitation zone of 10 to 16 inches (25 to 40 cm). Black sagebrush is usually associated with calcareous soils on dry sites, but can occur on mesic sites of the Douglas-fir zone in eastern Idaho. Silver sagebrush occurs primarily in spring-flooded bottomlands, and at high elevations where snow drifts. All species except three-tip sagebrush and silver sagebrush are nonsprouters. Three-tip sagebrush is a weak sprouter, silver sagebrush, a vigorous sprouter.

Major shrubs associated with big sagebrush include antelope bitterbrush (*Purshia tridentata*), horsebrushes (*Tetradymia* ssp.), rabbitbrush (*Chrysothamnus* sp.), and broom snakeweed (*Xanthocephalum sarothrae*). Spiny hopsage (*Grayia spinosa*) and mormon tea (*Ephedra nevadensis*) are sporadically present in the lower rainfall areas near the Salt Desert.

Dominant grasses include bluebunch wheatgrass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), needle-and-thread (*Stipa comata*), Thurber needlegrass (*Stipa thurberiana*), and to a lesser extent Indian ricegrass (*Oryzopsis hymenoides*). All of these species or only one may be present in a particular understory. Needle-and-thread and Indian ricegrass dominate sandy soils throughout the sagebrush-grass zone. On other soils, bluebunch wheatgrass dominates areas with moderate annual precipitation [9 to 14 inches (22 to 35 cm)] and Idaho fescue dominates the most mesic sites, generally those with more than 14 inches (35 cm) of annual precipitation. Temperature interacts with precipitation, so the moisture threshold that separates bluebunch wheatgrass from Idaho fescue can vary from 12 to 16 inches (30 to 40 cm) of precipitation annually. Thurber needlegrass occurs on medium-textured soils in an 8- to 12-inch (20- to 30-cm) precipitation zone. Sandberg bluegrass (*Poa sandbergii*) and bottlebrush squirreltail (*Sitanion hystrix*) are the most common subdominant bunchgrasses. Junegrass (*Koeleria cristata*) and other *Poa* spp. are also often present if the annual precipitation is above 11 inches (28 cm). Rhizomatous grasses that occupy localized areas include thickspike wheatgrass (*Agropyron dasystachyum*), plains reedgrass (*Calamagrostis montanensis*), and riparian wheatgrass (*Agropyron riparium*). Cheatgrass (*Bromus tectorum*), an introduced annual, occupies millions of acres on disturbed ranges (Klemmedson and Smith 1964). Medusahead (*Taeniatherum asperum*), another introduced annual, occupies disturbed clay sites that have well-developed profiles (Dahl 1966).

Forbs are present in great variety and abundance in climax communities where the precipitation is in excess of 11 to 12 inches (28 to 30 cm) per year. They may account for as much as 50 percent of the herbaceous production in eastern Idaho. For this reason herbicides, at least in our opinion, are undesirable to manage sagebrush-grass communities in eastern Idaho where balsamroot (*Balsamorhiza sagittata*) and lupine (*Lupinus* sp.) are typically the most abundant forbs. Forbs account for only 5 to 15 percent of the herbaceous vegetation in eastern Oregon. Groundsel (*Senecio* sp.), tapertip hawksbeard (*Crepis acuminata*), western yarrow (*Achillea millefolium*), and locoweed (*Astragalus* sp.) are the most common forbs and recover within 3 to 4 years after the use of herbicides (Sneva 1977, personal communication)[1].

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[1]Listed under unpublished references.

Fire History

Before the influence of man, fire covered contiguous units of sagebrush-grass communities in northern Yellowstone National Park at an average frequency of 32 to 70 years (Houston 1973). Within a large portion of this locale, however, fire swept smaller areas at least every 17 to 41 years. Dating all fires that occurred within a locale, Houston theorized that the frequency of fire in sagebrush communities within Yellowstone Park was 20 to 25 years. This estimated frequency was based on the assumption that the record of fire scars for any one tree underestimated the frequency of fire because not all trees were scarred by every fire. Houston's findings that many but not all trees had fire scars with similar dates suggests that once burned, an area was unlikely to have sufficient fuel to reburn for several years.

Based on the vigorous response of horsebrush (*Tetradymia canescens*) to fire and the 30-plus years that are needed for it to decline to a low level after a fire (Harniss and Murray 1973), probable frequency of fire would be about 50 years. If fires occurred every 20 to 25 years, as Houston implies, many sagebrush-grass communities could be dominated by horsebrush and rabbitbrush.

Ecological Effects of Fire

Grasses and Forbs

The effect of fire on grasses depends largely on growth form and season of burning. Bunchgrasses with densely clustered culms, such as Idaho fescue and needle-and-thread, can be severely harmed by fire (Blaisdell 1953; Wright 1971), especially if burned during June or July (Wright 1971). Their dense culms will burn 2 to 3 hours after a fire passes. Temperatures as high as 1,000°F (538°C) will be reached 45 min after a fire has passed (Wright 1971). Thus, many plants often die or have only a few culms that survive, regardless of the intensity of the passing fire. Late summer and fall burns are the least harmful.

Threadleaf sedge (*Carex filifolia*) also has a compact growth form and is severely harmed by fire (Vallentine 1971). Idaho fescue is very senstitive to summer and fall fires where the precipitation is marginal for its existence (Blaisdell 1953; Conrad and Poulton 1966). Preliminary research in eastern Oregon indicates that Idaho fescue will recover in 2 to 3 years if burned when the soil is moist in early spring (Britton and Sneva 1977, personal communication; Caraher 1977, personal communication).

Bluebunch wheatgrass; bottlebrush squirreltail, and the crested wheatgrasses (*Agropyron cristatum*, *A. desertorum*, and *A. sibericum*) are less susceptible to fire injury than Idaho fescue or *Stipa* sp. (Blaisdell 1953; Conrad and Poulton 1966; Wright 1971; Vallentine 1971) because the former are mostly coarse stems with a minimum of leafy material. They burn quickly and little heat transfers below the soil surface (Wright 1971). Moreover, the small size of Sandberg bluegrass and bottlebrush squirreltail in climax communities helps them survive fires (Wright and Klemmedson 1965); therefore they usually increase in abundance after a fire. All rhizomatous grasses such as thickspike wheatgrass and plains reedgrass increase immediately after a fire (fig. 3) (Blaisdell 1953). Production from rhizomatous grasses on burned plots will be above that on controls for about 30 years (Harniss and Murray 1973).

Figure 3.--Dense stand of thickspike wheatgrass and plains reedgrass 3 years after burning a mountain big sagebrush community near Dubois, Idaho. Patches of sagebrush in the background were not burned by the fire.

Bluebunch wheatgrass will return to preburn production in 1 to 3 years (fig. 4) (Blaisdell 1953; Moomaw 1957; Conrad and Poulton 1966; Uresk and others 1976; Daubenmire 1963, unpublished progress report); needle-and-thread in 3 to 8 years, depending on site (Blaisdell 1953; Dix 1960; Wright 1977, unpublished observation); and Idaho fescue in 2 to 12 or more years, depending on soil moisture, season, and intensity of the fire (Blaisdell 1953; Conrad and Poulton 1966; Harniss and Murray 1973; Britton and Sneva 1977, personal communication). The response of prairie junegrass (*Koeleria cristata*) to fire is similar to that of needle-and-thread (Vallentine 1971). Cusick bluegrass (*Poa cusickii*) is reduced 50 percent the first growing season after burning (Uresk and others 1976). Indian ricegrass (*Oryzopsis hymenoides*) is only slightly damaged by fire (Vallentine 1971).

Repeated burning every few years or burning in early summer will deplete a stand of perennial grasses and allow annual grasses, chiefly, cheatgrass (*Bromus tectorum*), to increase sharply (Pickford 1932; Wright and Klemmedson 1965). Once a sagebrush-grass community is depleted of perennial plant cover, secondary succession goes from Russian thistle (*Salsola kali*) to mustard (*Sisymbrium* and *Descurainia* sp.) to cheatgrass within 5 years (Piemeisel 1951). Pechanec and Hull (1945) found that burning near Boise, Idaho, reduced cheatgrass plants in varying numbers, depending on the month of the burn, as follows:

Burn	*Cheatgrass plants*	
Month	(ft^2)	(m^2)
June	14	15
July	11	12
August	41	44
October	45	48
November	124	133

The early summer burns are only a temporary setback for cheatgrass at a time of the year when climax perennials are easily killed by fire (Wright and Klemmedson 1965). Hence, the density of cheatgrass increases over time while fewer perennials survive after each fire.

Such areas can only be reclaimed by chemical fallow techniques (Eckert and Evans 1967) or plowing and then seeding. Most seeding has been done with wheatgrass (Hull 1971). Fairway wheatgrass (*Agropyron cristatum*), crested wheatgrass (*A. desertorum*), and Siberian wheatgrass (*A. sibericum*) are well adapted to this zone. Fairway wheatgrass is best adapted to moderately mesic sites and Siberian wheatgrass is best adapted to the driest sites in the 8- to 12-inch (20- to 30-cm) precipitation zone.

Figure 4.--Excellent stand bluebunch wheatgrass with a moderate amount of Basin big sagebrush in Idaho. Sagebrush communities like this one do not impede animal movements and do not need to be burned. (University of Idaho photo.)

Fall burning does not harm most forbs because many of them are dry and often disintegrated by this time. However, some forbs remain green and are very susceptible to fire. Pechanec and others (1954) classified forbs according to their susceptibility to fire (table 1). Unpublished data in Utah show that late summer or fall burning can kill Indian paintbrush (*Castilleja angustifolia*) (Frischknecht 1977, personal communication).

Table 1.--*Susceptibility of forbs to fire by three damaged classifications at Dubois, Idaho (Pechanec and others 1954)*

Severely damaged	Slightly damaged	Undamaged
Antennaria dimorpha	*Astragalus* sp.	*Achillea lanulosa*
Antennaria microphylla	*Castilleja angustifolia*	*Allium* sp.
Arenaria uintahensis	*Crepis acuminata*	*Arnica fulgens*
Erigeron engelmannii	*Geranium viscocissimum*	*Balsamorhiza sagittata*
Eriogonum caespitosum	*Lupinus caudatus*	*Comandra umbellata*
Eriogonum heracleoides	*Penstemon radicosus*	*Erigeron corymbosus*
Phlox canescens	*Sphaeralcea munroana*	*Lupinus leucophyllus*
		Phlox longifolia
		Senecio integerrimus
		Sisymbrium linifolium
		Zygadenus paniculatus

After 12 years, Blaisdell (1953) found that only the heavy sagebrush-grass burn (all sagebrush plants consumed by fire) supported more forbs than the control 12 years after burning. By the end of 30 years, forbs had returned to preburn levels (Harniss and Murray 1973), although both burned and unburned plots contained at least 5 times as many forbs as before the burn.

Shrubs

Fires can have a devastating and long-lasting effect on shrubs in sagebrush-grass communities. Big sagebrush, a nonsprouter, is highly susceptible to fire injury (Pickford 1932; Blaisdell 1953). Blaisdell found that the production of this species on burned areas in Idaho was only 10 percent of that on the control 12 years after the burn, but was near preburn levels 30 years after the burn (Harniss and Murray 1973). Some areas, however, recover much more quickly. Differences in recovery rates may be related to season of burn as it affects seed production (Johnson and Payne 1968), summer precipitation, and completeness of burn. Three-tip sagebrush is also damaged by fire, but some plants resprout (Blaisdell 1953).

Antelope bitterbrush is severely damaged by burning (fig. 5) (Blaisdell 1953; Pechanec and others 1954; Countryman and Cornelius 1957; Nord 1965). In Idaho 12 to 15 years after an experimental burn, antelope bitterbrush was still producing only 50 to 60 percent as much as the control (Blaisdell 1953). If soil is wet at the time of burning or shortly after the burn, antelope bitterbrush regularly resprouts (Blaisdell 1953; Blaisdell and Mueggler 1956; Nord 1965). If the plants resprout, they will regain original growth in 9 to 10 years (Blaisdell 1953). Where fires are not followed by rain, antelope bitterbrush seldom sprouts. In southern California, however, desert bitterbrush (*P. glandulosa*) resprouts vigorously and abundantly (Nord 1965) even without postfire rains.

Figure 5.--When bitterbrush (dark plants) is a major component of a plant community, burning should be carefully planned. Bitterbrush is easily damaged by fire and should either be protected from fire or burned when the soil is wet. Photo taken near Boise, Idaho.

Other species severely damaged by fire include cliffrose (*Cowania mexicana*), curlleaf mountain-mahogany (*Cercocarpus ledifolius*), granite gilia (*Gilia pungens*), and broom snakeweed (*Xanthocephalum sarothrae*) (Pechanec and others 1954; Vallentine 1971). Curlleaf mountain-mahogany is a weak sprouter (Monsen 1977 personal communication). Burning damages mountain snowberry (*Symphoricarpos orephilus*), but yield remains undamaged 15 years after burning (Pechanec and others 1954; Blaisdell 1953). Oregon grape (*Mahonia repens*) is favored by burning, especially after intense fires (Blaisdell 1953).

Rabbitbrush (*Chrysothamnus* sp.), a common genus in the sagebrush-grass zone, is usually enhanced by fire (Cottam and Stewart 1940; Blaisdell 1953; McKell and Chilcote 1957; Countryman and Cornelius 1957, Chadwick and Dalke 1965; Young and Evans 1974). An exception to this general response is apparent in rubber rabbitbrush (*Chrysothamnus nauseosus*). Robertson and Cords (1957) reported no recovery of this species 2 years after a burn on September 3, 1942, near Mono Lake, Calif., and after a burn on November 7, 1943, near McGill, Nev. However, burning in the latter area was repeated on an unburned area the following year on the same date and 95 percent of the plants resprouted. Evidently, the intensity of the fire is important because most of the sprouting after fire is epicormic (stem sprouting), not basal or root sprouting (Monsen 1977, personal communication).

Chrysothamnus viscidiflorus (all of its varieties and subspecies) resprouts vigorously. Generally, production is reduced for 1 to 3 years after burning, then it increases dramatically. On the U.S. Sheep Station near Dubois, Idaho, burning reduced production 59 percent the first year after burning (Blaisdell 1953). Three years after burning, production had doubled and was tripled at the end of 12 years (Blaisdell 1953). Similarly, Chadwick and Dalke (1965) found that the cover of *C. viscidiflorus* had increased 4 to 9 times on 8- to 18-year-old burns on sandy soils in northeast Idaho. Production of *C. bloomeri* (*C. viscidiflorus*) doubled 5 years after a burn in northern California (Countryman and Cornelius 1957). In western Nevada, Young and Evans (1974) found that green rabbitbrush (*C. viscidiflorus* var. *viscidiflorus*) continued to dominate burns and re-establish itself periodically for 15 years. Communities 40 to 50 years old were dominated by big sagebrush and contained reduced populations of green rabbitbrush.

Production of horsebrush (*Tetradymia canescens*) was reduced about 50 percent the first year after burning, but doubled at the end of 3 years (Blaisdell 1953). At the end of 12 years it had increased fivefold. After 30 years, many of these plants were dying out, but production was still 60 percent above that in the unburned control (Harniss and Murray 1973). Fire greatly enhances the dominance of this species.

Desirable shrubs such as serviceberry (*Amelanchier alnifolia*), snowbrush ceanothus (*Ceanothus velutinus*), and true mountain-mahogany (*Cerocarpos montanus*) are not damaged by fire (Vallentine 1971).

Management Implications

Prescribed fire can be a useful tool in many big sagebrush communities if the fires are carefully planned and livestock do not graze the burn for two growing seasons. Removal of tall, thick sagebrush by fire will greatly enhance movement of livestock and will release grasses and forbs from competition, resulting in increased yields. However, depending on the vegetation, fires should not be too frequent and should be planned in early spring or after late summer. Caution should be exercised where antelope bitterbrush is dominant and where horsebrush or rabbitbrush are abundant. Where forbs are abundant or sagebrush is tall and thick, fall burning may be preferred over chemical treatments as a management tool (figs. 6,7).

In the sagebrush-grass region, much burning can be done without firelines, especially where patches of big sagebrush grow in swales or in small ravines surrounded by low sagebrush. Fires will not carry in low sagebrush, even when winds are 20 mi/h (32 km/h). This condition is highly desirable because only big sagebrush growing on the most productive sites is burned and such burning creates an ideal mosaic for wildlife. Similarly, early spring burning can be done at higher elevations in pure stands of big sagebrush where snow patches can be used as firelines. Reduction of big sagebrush, but not low sagebrush, is desirable for game management. Livestock should be prevented from concentrating on the burned areas.

Burning followed by seeding will suppress medusahead, but the practice is not very successful where cheatgrass is dominant. Most cheatgrass areas must be treated with chemicals or plowed and then seeded if perennials are desired. Fire will convert pure stands of cheatgrass to native perennials. Likewise, pure stands of cheatgrass will not revert to native perennials with rest. Such areas have a high fire frequency and will decline in site potential (Young and others 1976).

Areas that are primarily sagebrush and cheatgrass can be successfully seeded after fire if the burns are hot enough to consume the sagebrush plants (Young and others 1976), and at the same time destroy cheatgrass seed. If much live cheatgrass seed remains, the burn should be chemically fallowed (Eckert and Evans 1967), or the germinating cheatgrass plowed before drilling with perennial wheatgrasses.

Figure 6.--Balsamroot and lupine make up a large component of the herbaceous yield in this three-tip sagebrush community. Fall burning would help to maintain the forb component.

Figure 7.--Dense stands of Basin big sagebrush suppress the yeild of herbaceous species and impede livestock movements. Fire would create variety in the habitat and enhance forbs and grasses. Photo taken in southern Idaho.

State-of-the-Art

We know generally how most shrubs and herbaceous species respond to fire in sagebrush-grass communities, but more information is needed on bluebunch wheatgrass, Idaho fescue, the big sagebrush subspecies, and bitterbrush. Fire intensity, season of burn, plant size, and soil moisture should be evaluated for several years at a variety of locations for bluebunch wheatgrass and Idaho fescue. More long-term fire effects data are badly needed for Idaho fescue.

Big sagebrush subspecies will sometimes invade burned areas rapidly and sometimes very slowly. McDonough and Harniss (1974) have studied the germination requirements of big sagebrush but more studies are needed. Timing of burns in relation to seed maturity, residual seed supply in soil after various intensities of heat, and response of sagebrush seed to soil moisture over a period of years all need to be evaluated. Sagebrush seed dispersal has been studied by Frischknecht (1962). He found that the mean maximum spread distance of big sagebrush seed was 42 ft (13 m) from parent plants.

We also need more research comparing spring and fall burns. Where forbs are not important in plant communities, early spring burning appears to be more favorable for bunchgrasses than late summer or fall burns.

Prescription data for sagebrush-grass burns have been given by Pechanec and others (1954) and more recently by Ralphs and others (1976). Nevertheless, the data needs to be strengthened. Proper fireline width is still unknown, and the potential for spot-fires in sagebrush-grass communities needs to be more thoroughly documented, although sagebrush is less volatile (Powell 1970) than chamise and pinyon-juniper.

PINYON-JUNIPER COMMUNITIES

Distribution, Climate, Soils, and Vegetation

The pinyon-juniper association covers from 43 to 76 million acres (17.4 to 30.8 million hectares) in Western North America, depending on whether you use Küchler's (1964) map (fig. 8) of potential pinyon-juniper woodland (the lower figure) or the earlier Senate Document 199 (Clapp 1936) wherein all western lands then having juniper, with or without pinyon pines, were included. West and others (1975) have taken a liberal definition of pinyon-juniper woodlands and included both Küchler's "juniper-pinyon woodlands" and "juniper steppe" types, plus the areas within the Great Basin sagebrush, sagebrush-grass steppe, and the Trans-Pecos shrub savannah where junipers are abundant. Leaving out the juniper woodlands in Texas, the figure by West and others (1975) for the Western United States is 75 million acres (30.4 million hectares). Except for the Central Great Basin where pinyon and juniper appear to be superimposed upon a large *Artemisia*/cool-season grass zone (Billings 1951), pinyon-juniper woodlands are located below the Gambel oak (*Quercus gambelii*) and ponderosa pine (*Pinus ponderosa*) zones, but above the sagebrush (*Artemisia* sp.) or grassland areas into which juniper, the least mesic of the two dominants, is continually spreading.

Pinyon-juniper woodlands extend from the east slope of the Sierra Nevada, eastward throughout the mountains of the Great Basin in Nevada and Utah, and on both flanks of the Rocky Mountains in Colorado (as well as mesas of the Colorado Plateau and interior valleys), then southward into Arizona, New Mexico, and northern Mexico (West and others 1975). Dense stands of juniper alone that join the pinyon-juniper woodlands extend further north into eastern Oregon, southern Idaho, and Wyoming.

Figure 8.--Distribution of pinyon-juniper woodlands in the southeastern United States after Küchler (1964).

Pinyon-juniper woodlands are generally found at elevations from 4,500 to 7,500 ft (1,372 to 2,287 m) (Springfield 1976), but they are best developed between 5,000 and 7,000 ft (1,524 to 2,134 m) (Woodbury 1947). Nevertheless, pinyon-juniper may be found growing from 2,500 to 3,000 ft (762 to 915 m) in the upper parts of deserts (Johnsen 1962; Franklin and Dyrness 1969) to 9,000 ft (2,744 m) in ponderosa pine forests (Lanner 1975). The highest elevation for pinyon-juniper woodland is nearly 10,000 ft (3,049 m) in the White Mountains of California, where the Sierra Nevada create an extreme rain-shadow effect (St Andre and others 1965). The upper altitudinal limit of the pinyon-juniper zone is determined by low temperature, and the lower range by a deficiency in moisture (Pearson 1920; Daubenmire 1947).

Annual precipitation varies from 10 to 15 inches (25 to 38 cm) over most of the pinyon-juniper zone where stands are open (fig. 9) (Woodbury 1947), but dense stands may receive 16 to 22 inches (40 to 55 cm) of rain and snow (Springfield 1976). On xeric sites at high elevations, annual precipitation of pinyon-juniper communities may be as high as 26 inches (65 cm) (Pearson 1931). Pinyon (*Pinus edulis* and *P. monophylla*) is usually most abundant at the higher elevations of the pinyon-juniper zone, with a mixing of pinyon and juniper at midelevations (Reveal 1944; West and others 1975; Springfield 1976). Because pinyon is very susceptable to fire damage (Leopold 1924), as well as being the more moisture-demanding of the two genera, fire, in addition to lower moisture, probably keeps pinyon out of the lower elevations.

Figure 9.--An open stand of pinyon-juniper with blue grama understory in eastern New Mexico.

Distribution of the pinyon-juniper association is not limited by parent material (Emerson 1932; Springfield 1976) or soil texture (Pearson 1931; Springfield 1976). The trees grow on residual and transported soils derived from sandstones, limestones, basalt, granite, and mixed alluvium (Springfield 1976). Soil textures vary from stony, cobbly, and gravelly loams to clay-loam and clay, and in depth from shallow to deep (Springfield 1976), but the best stands of pinyon are found on coarse gravel, gravelly loam, or coarse sands (Phillips 1909). The soils are generally calcareous and alkaline, but juniper grows well on acid soils down to a pH of 4.7 (Arend 1950). Except for those soils derived from basalt, most are low in fertility (Howell 1941; Springfield 1976) and often shallow and rocky.

Dominant tree species of the pinyon-juniper woodlands are Utah juniper (*Juniperus osteosperma*), one-seed juniper (*J. monosperma*), Rocky Mountain juniper (*J. scopulorum*), alligator juniper (*J. deppeana*), doubleleaf pinyon (*Pinus edulis*), and singleleaf pinyon (*P. monophylla*). Doubleleaf pinyon is associated with the Southern Rocky Mountains and extends westward to the eastern edge of the Great Basin. Throughout the Great Basin, eastern slope of the Sierra Nevada, and western portions of Arizona, singeleaf pinyon is associated primarily with Utah juniper.

Utah juniper is the most important of its genus in the pinyon-juniper woodland (Lanner 1975). Its range extends over northern Arizona, Utah, Nevada, and parts of California. One-seed juniper extends from central Colorado to central Arizona and it is widely distributed throughout most of New Mexico. Some one-seed juniper is found in the Palo Duro Canyon of West Texas. Alligator juniper, a sprouting species, is also widespread in the Southwest. It is abundant in Mexico and reaches its northern limits in north-central Arizona and New Mexico. Rocky Mountain juniper occurs only at the higher elevations of the pinyon-juniper woodland (Lanner 1975).

Outside of the pinyon-juniper woodland, western juniper (*J. occidentalis*) is very abundant in eastern Oregon. East of New Mexico, additional species of juniper such as redberry juniper (*J. pinchoti*), a sprouting species, Ashe juniper (*J. ashei*), and eastern red cedar (*J. virginiana*) are abundant. The latter junipers are usually associated with rocky slopes such as escarpments, ridges, or rimrocks throughout the Great Plains (Wells 1970), and alkaline soils such as the Edwards Plateau in central Texas. From the rocky areas where juniper is considered to be the climax in the Plains, trees have spread rapidly into the surrounding grasslands in the absence of fire. Eastern red cedar is the most extensive species and occurs from Texas northeastward throughout most of the Eastern United States.

Herbaceous species vary considerably throughout the pinyon-juniper zone. On the eastern flank of the Rocky Mountains in New Mexico, blue grama (*Bouteloua gracilis*) is the dominant herbaceous understory, with some sideoats grama (*B. curtipendula*) and wolftail (*Lycurus phleoides*) and a few forbs often intermixed (Pieper and others 1971). In north-central Arizona, blue grama and sideoats grama remain as dominant grasses, but prairie junegrass (*Koeleria cristata*), bottlebrush squirreltail (*Sitanion hystrix*), muttongrass (*Poa fendleriana*), and black dropseed (*Sporobolus interruptus*) are important components (Clary 1971). Other sites include desert needlegrass (*Stipa speciosa*) (Thatcher and Hart 1974), red threeawn (*Aristida longiseta*) and ring muhly (*Muhlenbergia torreyi*) (Jameson and Reid 1965), and western wheatgrass (*Agropyron smithii*) (Clary and Morrison 1973). Forbs and half shrubs make up about 50 percent of the herbaceous composition in north-central Arizona. Broom snakeweed (*Xanthocephalum sarothrae*), sulfur eriogonum (*Eriogonum cognatum*), plumweed birdbeak (*Cordylanthus wrightii*), and goldeneye (*Viguiera* sp.) are dominants (Clary 1971).

Northward, warm-season grasses drop out of the understory. In southwestern Colorado on Mesa Verde National Park, the meadow stage that develops 4 years after burning is dominated by Indian ricegrass (*Oryzopsis hymenoides*), bottlebrush squirreltail, and muttongrass (Erdman 1970). Forbs and shrubs are also present at various stages of succession after burning. In Utah, bluebunch wheatgrass (*Agropyron spicatum*) and western wheatgrass are the most abundant grasses, with lesser amounts of Sandberg bluegrass (*Poa sandbergii*), bottlebrush squirreltail, and Indian ricegrass (Barney and Frischknecht 1974). Forbs are a minor component.

Many sources (Blackburn and others 1969; Jensen 1972; Klebenow and others 1976) indicate that in Nevada common grasses include bottlebrush squirreltail, Sandberg bluegrass, needle-and-thread (*Stipa comata*), Great Basin wildrye (*Elymus cinereus*), and cheatgrass (*Bromus tectorum*). Other grasses include western wheatgrass, Indian ricegrass, and Thurber needlegrass (*S. thurberiana*). Forbs vary widely in species and abundance but can include *Lupinus* sp., *Phlox* sp., *Aster* sp., *Senecio* sp., *Eriogonum* sp., *Rannuculus* sp., *Cryptantha* sp., *Mentzelia* sp., *Eriastrum* sp., *Castilleja* sp., *Machaeranthera* sp., *Argemone* sp., *Sphaeralcea* sp., *Nicotiana* sp., *Lygodesmia* sp., and *Chenopodium* sp.

Further north in pure stands of western juniper in eastern Oregon, bluebunch wheatgrass and Idaho fescue (*Festuca idahoensis*) are the dominant grasses (Franklin and Dyrness 1969). Sandberg bluegrass and Thurber needlegrass are common. Other grasses include bottlebrush squirreltail, needle-and-thread, cheatgrass, annual fescue (*Vulpia octoflora*), and prairie junegrass. Forbs are not very abundant, but the most common perennial forbs are *Agoseris* sp., *Achillea millifolium*, *Eriophyllum lanatum*, *Astragalus* sp., *Erigeron linearis*, and *Lupinus* sp.

Herbage yields of pinyon-juniper stands can vary considerably, depending on surface texture of soil and stage of succession (Thatcher and Hart 1974). Soils with a vesicular, massive, or platy surface layer may have very little grass regardless of the stage of plant succession (Thatcher and Hart 1974). However, a reasonable average herbage yield for plant communities with moderate amounts of pinyon-juniper seems to be

600 lb/acre (674 kg/ha) (Jameson and Reid 1965; Jensen 1972; Pieper and others 1971; Clary 1971). Yields on good soils with good precipitation can be as high as 1,400 lb/acre (1,573 kg/ha) (Pieper and others 1971; Springfield 1976).

Shrubs that dominate the understory of pinyon-juniper include big sagebrush (*Artemisia tridentata*), black sagebrush (*A. nova*), antelope bitterbrush (*Purshia tridentata*), shrub liveoak (*Quercus turbinella*), cliffrose (*Cowania mexicana*), Gambel oak (*Quercus gambelii*), serviceberry (*Amelanchier* sp.), and true mountain-mahogany (*Cercocarpus montanus*). Other shrubs that are associated in various amounts with pinyon-juniper include fringed sagebrush (*Artemisia frigida*), Wright silktassel (*Garrya wrightii*), currant (*Ribes cereum*), desert peach (*Prunus andersonii*), mountain lover (*Pachistima myrsinites*), skunkbush sumac (*Rhus trilobata*), ephedra (*Ephedra* sp.), curl-leaf mountain-mahogany (*C. ledifolius*), chokecherry (*Prunus virginiana*), mockorange (*Philadelphus lewisi*), pointleaf manzanita (*Arctostaphylos pungens*), winterfat (*Ceratoides lanata*), snowberry (*Symphoricarpos vaccinoides*), algerita (*Berberis fremonti*), Wright eriogonum (*Erigonum wrightii*), rabbitbrush (*Chrysothamnus nauseosus*), Apache plume (*Fallugia paradoxa*), blackbrush (*Coleogyne ramosissima*), fourwing saltbush (*Atriplex canescens*), broom snakeweed, dalea (*Dalea* sp.), horsebrush (*Tetradymia canescens*), and yucca (*Yucca* sp.). This wide variety of shrubs reflects the many different plant communities with which pinyon-juniper associates and has been taken from various references (Arnold and others 1964; Dwyer and Pieper 1967; Blackburn and others 1969; O'Rourke and Ogden 1969; Blackburn and Tueller 1970; Erdman 1970; Aro 1971; Clary 1971; Barney and Frischknecht 1974; West and others 1975; Klebenow and Bruner 1976; Springfield 1976; Young and Evans 1976a).

Fire History

The historic role of fire in controlling the distribution of pinyon-juniper, particularly juniper, cannot be separated from the effects of drought and competition (Leopold 1924; Johnsen 1962; Burkhardt and Tisdale 1976). All three forces seem to have played a complementary role in limiting the distribution of juniper before grazing by domestic livestock was a factor. However, droughts and competition from grass probably only served to slow the invasion and growth of junipers in adajacent grasslands, because the trees are easily established during wet years (Johnsen 1962; Smith and others 1975), especially where shade is present (Meagher 1943). Then fire, occurring about every 10 to 30 years (Leopold 1924), kept the junipers restricted to shallow, rocky soils and rough topography (Arend 1950; Burkhardt and Tisdale 1969; O'Rourke and Ogden 1969). For the last 70 years, however, heavy livestock grazing has reduced grass competition as well as fuel for fires. Reduced competition from grasses has permitted pinyon and juniper to invade adjacent communities rapidly (Nabi 1978) and the reduced number of fires, each of a lower intensity than the fires before heavy grazing, has left the juniper invasion unchecked (fig. 10).

Figure 10.--Pinyon and juniper invading a sagebrush community in Nevada. (University of Nevada photo.)

Ecological Effects of Fire

Pinyon and juniper

The effect of fire on pinyon and nonsprouting juniper trees depends largely upon the height of trees, herbaceous fuel, weather conditions, and season. In open pinyon-juniper stands with an understory of 600 to 1,000 lb/acre (674 to 1,124 kg/ha) of fine fuel, Jameson (1962) and Dwyer and Pieper (1967) found that pinyon and juniper were easily killed by spring fires if trees were less than 4 ft (1.2 m) tall when air temperature was 70° to 74°F (21° to 23°C), relative humidity 20 to 40 percent and wind speed 10 to 20 mi/h (16 to 32 km/h). Lower air temperatures in January [49° to 54°F (9° to 12°C)], a relative humidity of 44 percent, and a wind speed of 6 to 8 mi/h (10 to 13 km/h) caused a very spotty burn in which crown kill for trees 2 to 4 ft (0.6 to 1.2 m) tall varied from 30 to 70 percent. Mortality 2 years after the burn, however, was 70 percent (Jameson 1962). A wildfire in June when air temperature was 97°F (36°C), wind was 10 to 15 mi/h (16 to 24 km/h), and relative humidity was 17 to 25 percent resulted in 100 percent kill of all trees less than 4 ft (1.2 m) tall, but was no more effective on taller trees than when air temperatures were 70° to 74°F (21° to 23°C) (Jameson 1962).

Trees taller than 4 ft (1.2 m) in open pinyon-juniper stands are difficult to kill unless heavy accumulations of fine fuel lie beneath the trees. On the wildfire studied by Dwyer and Pieper (1967), only 24 percent of the pinyon and 13.5 percent of the juniper that exceeded 4 ft (1.2 m) died. Jameson (1962) found that most juniper taller than 4 ft (1.2 m) had only a 30 to 40 percent crown kill, unless tumbleweeds had accumulated at the base of the trees. As a result of this added fuel, 60 to 90 percent of the crowns were killed, particularly for those of trees 8 to 10 ft (2.4 to 3.0 m) tall. East of the pinyon-juniper zone in Texas, juniper trees up to 12 ft (3.7 m) tall were killed easily when fine fuel was 2,000 lb/acre (2,247 kg/ha) or higher (Wink and Wright 1973).

Trees in closed stands of pinyon-juniper (fig. 11) with no grass or sagebrush in the understory are difficult to kill because fires do not carry easily (Arnold and others 1964; Blackburn and Bruner 1975). In 14- to 18-inch (35- to 45-cm) rainfall areas, dense stands [495 to 988 trees/acre (1,223 to 2,440/ha)] of mixtured pinyon-juniper can be burned on hot days, but pure stands of juniper are almost impossible to burn (Blackburn and Bruner 1975). In the Great Basin it is commonly believed that winds more than 35 mi/h (56 km/h) would be required to burn pure stands of juniper. Thus, many attempts to burn such stands have failed (Arnold and others 1964; Aro 1971). As the proportion of pinyon to juniper increases and the density increases, the stands are easier to burn (Truesdell 1969; Blackburn and Bruner 1975).

Figure 11.--Dense, closed stand of pinyon and juniper with no understory, in Nevada. (University of Nevada photo.)

Mixtures of sagebrush and pinyon-juniper are common throughout the Great Basin, and it is feasible to burn and kill large pinyon and juniper trees in these communities (Bruner and Klebenow 1979). Most of the work done by Bruner and Klebenow has been done in pinyon-juniper stands with 45 to 60 percent shrub and tree cover when air temperature was 60° to 75°F (16° to 24°C), relative humidity was below 25 percent, and maximum wind speed was 5 to 25 mi/h (8 to 40 km/h).

Alligator juniper and redberry juniper are the only sprouting species. Smith and others (1975) found that if the tops of redberry juniper trees were removed before they reached 12 years of age, 99 percent mortality could be expected. Older trees were not studied. This data implies that if subjected to fire every 10 years or so, sprouting species of juniper may have a difficult time invading grasslands. Schroeder (1956 unpubl.) found that about 40 percent of alligator juniper trees less than 15 ft (4.6 m) tall could be killed by burning individual plants.

Grasses and Forbs

In Utah the most abundant annual forbs during the first stage of succession are pale alyssum (*Alyssum alyssoides*), flixweed tansymustard (*Descurainia sophia*), sunflower (*Helianthus annuus*), coyote tobacco (*Nicotiana attenuata*), and Russian thistle (*Salsola pestifer*) (Barney and Frischknecht 1974). Generally, however, none of these forbs constitute a large amount of cover on pinyon-juniper burns (Arnold and others 1964; Barney and Frischknecht 1974). Cheatgrass brome (*Bromus tectorum*) is usually the most abundant annual and has a cover value as high as 12.6 percent on 3-year-old burns. Thereafter, it gradually declines to 0.9 percent over a period of 20 years (Barney and Frischknecht 1974). On some sites, however, cheatgrass may never show up (Klebenow and others 1976) which might be used as a guide as to whether some areas can be reclaimed to grasses. In Nevada, tapertip hawksbeard (*Crepis acuminata*) and *Lupinus* sp. increase abundantly after fire (Klebenow and others 1976). *Balsamorhiza* sp. and *Castilleja* sp. also come back reasonably well (Klebenow and others 1976).

The composition of perennial grasses varies with location, as discussed earlier. In the northern latitudes west of the Rocky Mountains, cool-season grasses dominate, with a gradual transition to dominance of blue grama eastward in shortgrass plains and southward in central Arizona and New Mexico. Vallentine (1971) has cited a number of authors as to the tolerance of various grasses to fire. Species that are only slightly damaged by fall fires include bluebunch wheatgrass, Indian ricegrass, galleta grass (*Hilaria jamesii*), bottlebrush squirreltail, Great Basin wildrye, and blue grama. Those moderately affected by fire include prairie junegrass, needle-and-thread, Thurber needlegrass, and threeawns. Species severely affected by fire include ring muhly, sideoats grama, and Idaho fescue. Sandberg bluegrass, cheatgrass, western wheatgrass, and crested wheatgrass are unaffected by fall fires.

Shrubs

Vigorous sprouters after fire include serviceberry, Wright silktassel, shrub live-oak, skunkbush sumac, true mountain-mahogany, desert bitterbrush, chokecherry, mockorange, winterfat, snowberry, algerita, rabbitbrush, fourwing saltbush, and horsebrush. Weak sprouters include antelope bitterbrush, curlleaf mountain-mahogany, snakeweed, mountain lover, yucca, fringed sagebrush, and Wright eriogonum. Antelope bitterbrush and mountain lover are extremely slow in recovering after fire (Nord 1965; McKell 1950). Cliffrose is eliminated on burns in Nevada (Klebenow and others 1976). Nonsprouting species include big sagebrush, black sagebrush. and blackbrush. Nevertheless, these nonsprouting species, except for blackbrush, have the ability to reestablish themselves quickly from seed. Blackbrush reestablishes very slowly (Bowns and West 1976; Jensen and others 1960, unpublished report).

Succession after Fire

The general successional pattern after fire in pinyon-juniper of the Southern Rocky Mountains has been worked out by Arnold and others (1964) and most recently by Erdman (1970) and Barney and Frischknecht (1974). The order of vegetational changes in juniper woodland after fire as reported by Barney and Frischknecht is as follows: juniper woodland → fire → skeleton forest (dead trees) and bare soil → annual stage → perennial grass-forb stage → perennial grass-forb-shrub stage → perennial grass-forb-shrub-young juniper stage → shrub-juniper stage → juniper woodland.

Mature stands of juniper (100+ years) consist primarily of 35 percent bare-ground, 19 to 60 percent litter, a tree overstory that inhibits grass production (Johnsen 1962), and a few scattered shrubs and perennial and annual grasses (Arnold and others 1964; Clary 1971; Barney and Frischknecht 1974). Erosion is frequently a problem from the bare soils between trees in mature stands (Plummer 1958). After a fire, juniper seedlings and annuals begin to invade and reach maximum abundance in the first 3 to 4 years (Arnold and others 1964; Barney and Frischknecht 1974). Where partial shade is present, pinyon seedlings can also be abundant (Erdman 1970). The perennial-grass-forb stage usually follows in the fourth to sixth year. Little rabbitbrush (*Chrysothamnus viscidiflorus*) resprouts in the first year or two, and shrubs such as sagebrush (*Artemisia* sp.) and broom snakeweed (*Xanthocephalum sarothrae*) if they are present in the area begin appearing after the sixth year in plant communities in and around the Great Basin. In southwestern Colorado, Gambel oak, serviceberry, true mountain-mahogany, and antelope bitterbrush are the dominant shrubs (Erdman 1970). After 40 years, the shrubs begin to die out and the cover and density of juniper increases dramatically (Barney and Frischknecht 1974). Barney and Frischknecht (1974) found that Utah juniper begins to bear fruit at 33 years of age, which accounts for the ability of many juniper stands at 40 years of age or older to establish new trees and increase the number of trees per acre dramatically (Erdman 1970).

According to Erdman (1970), plant succession continues in three more stages. The open shrub stage becomes a thicket in about 100 years. As the sere progresses toward climax, the trees begin to overtop the shrubs and gradually suppress the shrubs as the forest matures. After several centuries, the understory is composed mainly of a sparse shrub component, some grass, and several forbs. In the absence of disturbances, a climax pinyon-juniper forest occurs in about 300 years.

Management Implications

In open stands of pinyon-juniper in the Southwest, fire can be used effectively to kill pinyon and juniper trees less than 4 ft (1.2 m) tall. Taller trees are very difficult to kill, even with hot fires, unless tumbleweeds have accumulated at the tree bases. Thus, open stands of pinyon and juniper trees can be eliminated only by chaining or dozing followed by burning to render the microclimate unfavorable for tree seedlings.

Several management agencies have tried various techniques (Arnold and others 1964; Aro 1971; Clary 1971; Blackburn and Bruner 1975) to reclaim closed pinyon-juniper stands (no understory of grasses or shrubs). Prescribed burning, or some combination of burning with other treatments (followed by artificial seeding when necessary), is the most effective procedure (Aro 1971; Springfield 1976). Without any prior treatment, burning must be done on hot days 95° to 100°F (35° to 38°C) with low relative humidity and 8 to 20 mi/h (13 to 32 km/h) winds, conditions considered too hazardous by most land managers (Arnold and others 1964). Thus, mechanical treatment followed by burning is probably the most acceptable technique to reclaim dense stands of pinyon-juniper, even though it is expensive. Burning should be delayed 2 to 3 years after chaining to assure that most of the pinyon and juniper seeds have germinated (Meagher 1943).

Grasses will increase dramatically following burning and seeding treatments in closed stands of pinyon-juniper. Herbage yields on the Hualpai Indian Reservation in northern Arizona, seeded with crested wheatgrass, western wheatgrass, weeping lovegrass, and yellow sweetclover (*Melilotus officinalis*), produced 1,660 lb/acre (1,865 kg/ha) compared to 60 lb/acre (67 kg/ha) for the unburned control (Aro 1971). On another large-scale burning and seeding program in pinyon-juniper woodland, Aro (1971) reported that forage production increased 500 lb/acre (562 kg/ha). Pinyon-juniper communities in northern Arizona that were chained and seeded but not burned produced 981 lb/acre (1,102 kg/ha) of grasses, forbs, and shrubs 5 to 11 years after treatment, compared to 223 lb/acre (250 kg/ha) on control plots (Clary 1971). Where native grasses were present in the understory, reseeding was not necessary (Aro 1971).

Mixtures of sagebrush and pinyon-juniper can be burned without prior treatment. Generally, thick stands with 45 to 60 percent cover are selected for burning and burned into areas with less shrub cover. Some areas are left to reseed naturally, but aerial seeding is usually considered desirable.

Pinyon-juniper stands converted to grassland should be reburned about every 20 to 40 years. A definite time is difficult to set because reinvasion of pinyon and juniper is dependent on climate, kind of initial treatment, time span between treatments, intensity of the burn, and grazing intensity after the burn. A general guide would be to reburn when the tallest pinyon or juniper tree reaches a height of 4 ft (1.2 m).

State-of-the-Art

More research is needed on techniques for burning closed stands of juniper and mixed stands of sagebrush and pinyon-juniper. Although we have a general knowledge of, and procedures for prescribed burning, we are not satisfied with either. Closed stands have been burned successfully and economically in northern Arizona without prior treatment, but we need to know where this kind of burning can and cannot be done. Can the technique be applied to areas with less than 200 trees per acre (494 trees per hectare) or areas with less than 600 lb/acre (674 kg/ha) of herbaceous understory? Some reliable guides are needed.

We have reasonably good baseline data for burning mixed stands of pinyon-juniper and sagebrush with no herbaceous understory. However, we need to know more about setting the boundaries (based on cover and weather) for areas to be burned. Should firelines be chained and burned before burning a large block of mixed sagebrush and pinyon-juniper? How wide should the firelines be?

We know reasonably well how to burn open pinyon-juniper grasslands. We need to know the minimum amount of fine fuel (herbaceous understory) that will carry a fire. Our estimate is 600 to 700 lb/acre (674 to 786 kg/ha), which is about the productive potential of a large percentage of the pinyon-juniper acreage.

Our largest void of information on pinyon-juniper communities is the response of the understory species to fire. We have pieces of information, but a number of the shrubs and some cool-season grasses deserve more study. Alligator juniper needs to be studied in more detail. We need to know how different age classes of this species respond to fire. Our present data indicate that young trees may be more susceptible to fire than the old trees.

Guidelines for reseeding burned pinyon-juniper stands would be helpful. Should drilling be done in preference to aerial seeding when possible? In untreated pinyon-juniper at what point is it advisable to supplement the natural perennial understory with artificial seeding?

PRESCRIBED BURNING GUIDES

Sagebrush-Grass Communities

Big Sagebrush and Grass

Sagebrush is difficult to burn unless there is at least 600 to 700 lb/acre (674 to 786 kg/ha) of herbaceous fuel (Beardall and Sylvester 1976). Moreover, burning should not be considered a management tool unless the cover of big sagebrush exceeds 20 percent (Pechanec and others 1954). After deciding to burn, try to avoid burning immediately after heavy seed crops, because sagebrush can rapidly reoccupy the burned area during years with good moisture (Pechanec and others 1954; Johnson and Payne 1968). Early spring or late summer (August) burns may be the most preferable (Blackburn and Bruner 1975; Beardall and Sylvester 1976). Soils should be moist down to 12 or 18 inches (30 to 45 cm) before burning in the spring, but in the fall soil moisture is not as critical for most plant species.

Various procedures have been used to conduct prescribed burns in sagebrush-grass communities. In southeastern Idaho Pechanec and others (1954) plowed a single 8-ft (2.4-m) fireline completely around an area. On the downwind edge of the fireline, they plowed another line with the berm pushed to the center of the plowed area to stop firebrands rolling along the ground. Then Pechanec and others (1954) plowed a final line 100 to 200 ft (30 to 61 m) inside the area to be burned, parallel to the double fireline. This uncleared strip [usually the north and east sides of a 400- to 600-acre (162- to 243-ha) block] was burned in late August with backfires or strip headfires in the forenoon, with the wind 5 to 8 mi/h (8 to 13 km/h) and relative humidity about 40 percent. After the uncleared strip had been burned, the remaining area was burned with a headfire, starting about 2:30 to 3:00 p.m., presumably when air temperature was above 75°F (24°C), relative humidity was 15 to 20 percent, and wind was 8 to 15 mi/h (13 to 24 km/h) (Ralphs and others 1976).

A burning technique similar to that of Pechanec and others (1954) was used at the Benmore Experimental Range in central Utah (Blackburn and Bruner 1975). Firelines varied from 20 to 150 ft (6.1 to 45.7 m), with the narrow lines being on the upwind side (Davis 1976). Davis (1976) states that based on theoretical values and experience, flash fuels can be expected to ignite 50 to 90 ft (15.2 to 27.4 m) ahead of an advancing front in sagebrush-grass. However, he has seen spot fires start 200 ft (61 m) in advance of the flame front (Davis 1978, personal communication). This implies that firelines on the downwind side of a sagebrush-grass fire should be at least 200 ft (61 m) wide.

Martin and others (1977) have used a wet line in lieu of a plowed line in cheatgrass (*Bromus tectorum*). This technique involves wetting a line and letting the fire back away from it. This can be done easily in cheatgrass on smooth terrain; however, in rough topography, this technique would not be feasible. More attention needs to be given to the preparation of safe firelines without the use of dozers (Davis 1976). Fire retardants and the use of chemicals are alternatives, but have not been adequately tested to be recommended.

Recommendation: Based on the above data and research by Ralphs and others (1976) we recommend dozing a 10- to 12-ft (3- to 3.7-m) fireline around the area to be burned [preferably about 450 acres (182 m) according to Davis (1976)]. Then strip headfire a 200 ft (61 m) strip on the leeward sides during the morning hours when wind is 5 to 8 mi/h (8 to 13 km/h) and relative humidity is about 40 percent. As the fire backs up in heavy fuel beyond the 200 ft (61 m) strip, use a pumper to put the fire out. About 2:00 p.m. headfire the remaining area when air temperature is above 75°F (24°C), relative humidity is 15 to 20 percent, and wind is 8 to 15 mi/h (13 to 24 km/h) (Ralphs and others 1976).

Big Sagebrush and Low Sagebrush

Where dense stands of big sagebrush are mixed with low sagebrush (*Artemisia arbuscula*) (fig. 12), no firelines need to be prepared because fires will not carry in low sagebrush even during a hot day with winds up to 25 mi/h (40 km/h) (Beardall and Sylvester 1976). Thus, such stands can be burned on warm days with steady winds whenever it is convenient.

Recommendation: Beardall and Sylvester (1976) suggest burning in early spring when relative humidity is below 60 percent, wind speed is above 8 mi/h (13 km/h), and when there is more than 600 to 700 lb/acre (674 to 786 kg/ha) of fine fuel. Late summer burning has not been tested in areas dominated by low sagebrush because of the potential to harm sensitive grasses such as Idaho fescue (*Festuca idahoensis*).

Figure 12.--Low sagebrush community with Idaho fescue. Fine fuel is usually inadequate to carry a fire. (University of Idaho photo.)

Pinyon-Juniper Communities

Open Stands of Pinyon-Juniper with Grass Understory

In this vegetation type, fire kills only pinyon and juniper trees less than 4 ft (1.2 m) tall (Jameson 1962; Arnold and others 1964; Dwyer and Pieper 1967). Moreover, we believe that at least 600 to 700 lb/acre (674 to 786 kg/ha) of fine fuel is needed to carry a fire. Trees taller than 4 ft (1.2 m) will not be killed unless tumbleweeds have accumulated at the base (Jameson 1962).

Recommendation: Doze a fireline 10 to 12 ft (3.0 to 3.7 m) wide around the area to be burned. About 450 acres (182 ha) would be a good-sized unit (Davis 1976). Strip headfire a 100-ft (30-m) strip on the leeward sides of the planned burn during evening or morning hours in the spring. Where fire continues to back up beyond the 100-ft (30-m) strip, put it out with a pumper. Then headfire the remainder of the area when the air temperature is 70° to 74°F (21° to 23°C), relative humidity is 20 to 40 percent, and windspeed is 10 to 20 mi/h (16 to 32 km/h) (Jameson 1962; Dwyer and Pieper 1967).

Closed Stands (No Grass or Shrub Understory) of Pinyon and Juniper

Mixtures of pinyon and juniper with 300 or more trees per acre (741 or more trees per hectare) in 14- to 18-inch (35- to 45-cm) rainfall areas can be burned on hot, windy days if prepared properly (Truesdell 1969; Blackburn and Bruner 1975). However, closed stands of juniper are almost impossible to burn (Blackburn and Bruner 1975) and would probably require winds in excess of 35 mi/h (56 km/h) to carry a fire. As the proportion of pinyon to juniper increases and density increases, the stands are easier to burn (Hester 1952; Truesdell 1969; Blackburn and Bruner 1975).

Recommendation: Where firebrands are not a problem on a hot day (i.e., burning into the Grand Canyon or on top of a mesa), prepare dense stands of pinyon and juniper for burning in March or April. Clear a strip 20 to 50 ft (6.1 to 15.2 m) wide every 0.25 mile (0.4 km) and push windrows against the green trees on the windward side. Let the material cure for 60 to 90 days. Then in late June or early July, burn when temperatures vary from 80° to 95°F (27° to 35°C), relative humidity is 4 to 8 percent, and winds exceed 8 mi/h (13 km/h) (Truesdell 1969; Blackburn and Bruner 1975).

Where firebrands are of concern, or where the pinyon-juniper stands are predominantly juniper, a more acceptable method of killing trees in closed stands may be to chain, burn, and seed (Aro 1971; Stinson 1978). Two or three months after chaining, pinyon and juniper can be burned with little risk when the wind is blowing into an untreated closed stand (fig. 13) or into a recently treated area with little fine fuel. Burn the lee sides of the area (61 m) during the morning hours when the fire danger is low (Stinson 1978). Then, burn the remainder of the area under the following conditions: air temperature 90° to 100°F (32° to 38°C), relative humidity less than 10 percent, wind 8 to 10 mi/h (13 to 16 km/h) (Stinson 1978).

It takes large crews to do this kind of burning because much of the material is in piles or windrows. Burning chained areas removes the trash and young trees that provide an ideal microenvironment for the establishment of pinyon and juniper seedlings (Meagher 1943) and also provides a good seedbed for grasses.

Another alternative for closed pinyon and juniper stands is to use chaining to construct firelines (Davis 1976). Optimum width is not known. A 300-ft (91-m) line should be adequate because there is very little fine fuel that can be ignited by glowing embers. The lines could be chained in the winter and then burned under moderate conditions in the spring or summer when surrounding vegetation is green (Davis 1976). Weather with temperatures of 60° to 75°F (16° to 24°C), windspeed less than 8 mi/h (13 km/h), and relative humidity about 25 percent should be adequate for burning such firelines, although this has not been documented. It would seem preferable to burn under cool conditions so that most of the manpower could be used to light the dead material, rather than to patrol for spotfires.

After the firelines have been burned out, then the windrows (also prepared in winter) on the upwind side could be lit on a dry, hot, windy day in June or July. Air temperatures should be 80° to 95°F (27° to 35°C), relative humidity 4 to 8 percent, and windspeed in excess of 8 mi/h (13 km/h).

Figure 13.--Burning into closed stands of juniper such as this one should be reasonably safe because little fine fuel is on the ground.

Mixture of Pinyon-Juniper and Sagebrush

Mixtures of sagebrush and pinyon-juniper are common throughout the Great Basin. Dense patches of pinyon-juniper and sagebrush that vary in size from 5 to 60 acres (2 to 24 ha) can easily be burned without preparing firelines (Bruner and Klebenow 1979).

Recommendation: Klebenow and Bruner (1976) have found that mixtures of pinyon-juniper and sagebrush with a total shrub and tree cover of 45 to 60 percent can be burned when spring air temperatures vary from 60° to 75°F (16° to 24°C), relative humidity is below 25 percent, and maximum windspeeds vary from 5 to 25 mi/h (8 to 40 km/h). They recommend using the "White Pine County Formula" to determine whether or not to burn (Bruner and Klebenow 1979) where,

Index = Maximum wind (mi/h) + Shrub and tree cover (%) + Air temperature (°F).

If the index is 110 or higher, a fire will carry and will kill large pinyon and juniper trees. If the index is above 130, it is too dangerous to burn. Retorching of trees is necessary until the index is over 125.

FIRE EFFECTS DATA FOR PLANT SPECIES

Response of Grasses to Burning

Bluegrasses

In general, bluegrasses (*Poa* sp.) are slightly damaged by burning. Wright and Klemmedson (1965) observed no change in basal area of Sandberg bluegrass (*Poa sandbergii*) during any season regardless of the size of plants. These plants were mature, dry, and varied in diameter from 1 to 3 inches (2.5 to 7.5 cm). Tisdale (1959) reported some damage to Sandberg bluegrass in communities with 7 to 14 percent sagebrush cover. This damage was possibly caused by plants being old and pedestaled. High mortality has been observed in southern Oregon when plants are pedestaled (Hammersmark 1977, personal communication). An August wildfire in northeastern California caused decreases in plant numbers (Countryman and Cornelius 1957). Moomaw (1957) found no damage in eastern Washington. Uresk and others (1976) measured a 57 percent decrease in basal area of cusick bluegrass (*P. cusickii*) after an August wildfire.

On the upper Snake River Plains of Idaho, Nevada bluegrass (*P. nevadensis*) and Sandberg bluegrass showed little change in production for 3 years after burning (Harniss and Murray 1973). This initial static period was followed by increased yields, with the burned area producing about 1.5 times more than the unburned. Thirty years after burning, yield was substantially lower on both burned and unburned areas, although the burned area was producing twice as much as the unburned. Big bluegrass (*P. ampla*) is not mentioned in the literature but, due to larger clone size and greater potential accumulation of litter in the crown, it would be expected to incur slightly more damage than other bluegrasses.

Cheatgrass

Cheatgrass (*Bromus tectorum*) is not appreciably affected by burning although production may be reduced for the first year. Abandoned fields on the Snake River Plains dominated by cheatgrass were changed to primarily tumblemustard (*Sisymbrium altissimum*) and Russian thistle (*Salsola kali*) after burning for 2 to 3 years. Cheatgrass dominated these fields during the next 2 to 3 years (Piemeisel 1938). Burning was found to reduce stands of cheatgrass in eastern Washington, presumably because of seed destruction (Robocker and others 1965). Depending on the intensity of burn, germinable cheatgrass seed can be reduced 80 to 99 percent (Young and others 1976). This reduction left from 3 to 33 germinable seeds/ft^2 (32 to 374/m^2), but as few as 5 cheatgrass seeds/ft^2 (54/m^2) moderately reduced establishment of crested wheatgrass. June and July burns reduced cheatgrass plant numbers to 14 and 11/ft^2 (150 and 118/m^2) compared to 41, 45, and 124 plants/ft^2 (439, 481, and 1,327 plants/m^2) on August, October, and November burns, respectively, near Boise, Idaho (Pechanec and Hull 1945). These reductions are only temporary, for annuals produce abundant seed the year after a burn. Early summer burns will kill perennial grasses and allow cheatgrass to increase sharply.

Cheatgrass can rapidly occupy a burned area if only a few seeds are available (Countryman and Cornelius 1957). Barney and Frischknecht (1974) reported that cheatgrass cover declined during the first 22 years after fire, then stablized. This cover change varied from 12.6 percent on 3-year-old burns to 0.9 percent on the oldest burns.

Idaho Fescue

The majority of evidence indicates that Idaho fescue (*Festuca idahoensis*) is severely damaged regardless of when or where it is burned (Pechanec and Stewart 1944; Blaisdell 1953; Harniss and Murray 1973). After a period of 30 years, Idaho fescue was just approaching its former abundance on the upper Snake River Plains (Harniss and Murray 1973). However, the annual precipitation is 14 in (35 cm) in this area, which is marginal for Idaho fescue in this region of Idaho. As a result of a summer wildfire in eastern Washington, Idaho fescue mortality was 27 percent, with a reduction in basal area of 50 percent (Conrad and Poulton 1966). In northeastern California, basal area of Idaho fescue was reduced approximately 80 percent by an August wildfire (Countryman and Cornelius 1957).

Mid-May burns in eastern Oregon resulted in 30 percent mortality and a 48 percent reduction in basal area (Britton and Sneva 1977, personal communication). However, when the plants were dormant in the fall, no mortality resulted although there was a 34 percent reduction in basal area. Phillips (1977, personal communication) observed that in central Oregon, wildfires were more damaging to Idaho fescue on coarse soils than on fine-textured soils. Good soil moisture was found beneficial to Idaho fescue survival during spring burns in Nevada (Beardall and Sylvester 1976).

Indian Ricegrass

Indian ricegrass (*Oryzopsis hymenoides*) is important in sagebrush-bunchgrass communities only in localized situations. As such, it has not been the subject of intensive investigations. Pechanec and Stewart (1944) mention it as being slightly damaged and slow to increase after burning.

In west-central Utah, Indian ricegrass was found to be an important species on burned areas (Barney and Frischknecht 1974). Therefore, it probably has good survival characteristics. Spring burning in Utah did little damage to Indian ricegrass; growth began about 3 weeks after burning (Jensen 1977, personal communication). Summer wildfires in Nevada reduce basal area, but little mortality was noted (Wagner 1977, personal communication).

Junegrass

In eastern Oregon, junegrass (*Koeleria cristata*) has been found to be one of the most fire-resistant perennial bunchgrasses (Britton and Sneva 1977, personal communication). Burning in mid-May reduced basal area by 32 percent, with 20 percent mortality. Burning in mid-June just after seed-set reduced basal area 18 percent, with no mortality; burning in mid-October produced only slightly more damage. Light damage is probably due to the relative small size of the typical junegrass clone.

Fall burning in North Dakota increased the frequency of junegrass on a sandy soil (Dix 1960). Twelve years after burning in Idaho, junegrass yield was higher on burned areas than on unburned areas (Blaisdell 1953). Countryman and Cornelius (1957) reported a slight decrease in junegrass due to a wildfire although the sample was too small for adequate interpretation.

Needlegrasses

Most needlegrasses (*Stipa* sp.) are damaged by burning, especially during the first year. Harniss and Murray (1973) reported a severe reduction the first year after burning needle-and-thread (*Stipa comata*). Season of burn rather than burning intensity or plant size was found to be the most critical factor in mortality of needle-and-thread (Wright and Klemmedson 1965). June burns killed all of the small plants and 90 percent of the large plants. In July, 20 percent of the burned plants died but no mortality was

recorded for August treatments. Among large plants, the average basal area reduction after June burns was 99.6 percent; July burns, 96 percent; and August burns, 68 percent. The reduction in basal area for the small plants following June burns was 100 percent, July burns, 82 percent. Small plants burned in August exhibited some thinning of the crown. This damage was related to the intolerance of needle-and-thread grass to herbage removal and the large amounts of dead material per unit basal area (Wright 1971). In western North Dakota, fall burning decreased needle-and-thread grass frequency by 11 percent on sandy soils but increased frequency by 10 percent on a clayloam soil. Observations in southern Idaho indicate that with moderate grazing treatments, needle-and-thread grass requires 4 to 8 years after burning to fully recover.

Twelve years after burning, Blaisdell (1953) observed that needle-and-thread grass and Columbia needlegrass (*S. columbiana*) were not significantly affected by any intensity of burn, although the former produced 10 to 26 lb/acre (11 to 29 kg/ha) on burned than on unburned range. Western needlegrass (*S. occidentalis*) was reduced the first year after an August wildfire in northeastern California (Countryman and Cornelius 1957). By the third year after burning, western needlegrass had almost doubled in basal area as compared to the unburned area.

Thurber needlegrass (*S. thurberiana*) is probably the least fire resistant needlegrass. Uresk and others (1976) found that an August wildfire reduced the basal area by 53 percent, with a concurrent decrease in leaf length. In eastern Oregon, Thurber needlegrass was severely damaged by burning (Britton and Sneva 1977, personal communication). Plants burned in mid-May had 80 percent mortality and the basal area was reduced by 93 percent. In mid-June, mortality increased to 90 percent and basal area was reduced 93 percent. Least damage resulted from October burns, with no mortality and a 48 percent reduction in basal area. Wright and Klemmedson (1965) reported similar results for Thurber needlegrass.

Sedges

Sedges show various responses to burning. Pechanec and Stewart (1944) list threadleaf sedge (*Carex filifolia*) as being severely damaged; Douglas sedge (*C. douglasii*) was classed as undamaged. This difference was attributed to the ability of Douglas sedge to initiate growth from basal buds. Twelve years after burning, Blaisdell (1953) reported sedges were producing more on light burns but less on moderate and heavy burns in one area while the opposite trend was found on another area. Threadleaf sedge was found to be producing on the average more on burned areas as compared to unburned areas, therefore initial damage by burning was not permanent. Douglas sedge was reduced in number of plants as a result of a wildfire in northeastern California (Countryman and Cornelius 1957).

Bottlebrush Squirreltail

Bottlebrush squirreltail (*Sitanion hystrix*) is one of the more fire resistant bunchgrasses, although some damage is apparent. In southern Idaho, Wright and Klemmedson (1965) observed no plant mortality as a result of burning. There was some reduction in basal area for plants burned in June but it was most apparent (15 percent reduction) in July for both large and small plants. In August only the large plants responded to hot burns, with a 16 percent reduction in basal area. The greater overall damage in July was probably due to higher initial burn temperatures in the plant crown. Wright (1971) reported that burning generally reduced herbage production of bottlebrush squirreltail most during May and somewhat less thereafter. In northeastern California, bottlebrush squirreltail plants were found to increase in winter the first year after wildfire but decreased by the third year (Countryman and Cornelius 1957).

Burning bottlebrush squirelltail plants in a drought year in eastern Oregon resulted in 30 percent mortality in mid-May (Britton and Sneva 1977, personal communication). No mortality was recorded for mid-June or October burns. The mid-May burns reduced basal area by 73 percent while the October burn reductions were 48 percent.

In west-central Utah, bottlebrush squirelltail cover was found to increase during the first 5 to 6 years after burning (Barney and Frischknecht 1974). This increase was stable for up to 40 years. Often bottlebrush squirelltail plants are very small and will increase in size rapidly after a burn. The larger plants, however, would be slightly harmed (Wright 1971; Britton and Sneva 1977, personal communication).

Wheatgrasses

Fall burning of crested wheatgrass (*Agropyron desertorum*) results in only small changes in the stand. Density of plants should remain unchanged (Kay 1960), although yield may be reduced during the first growing season after burning (Lodge 1960). After growth initiation, spring burning can reduce yield for 2 years (Lodge 1960). Crested wheatgrass seedings are considered fire resistant because many observers report that wildfires move only a few feet (2 or 3 m) into a seeding.

Bluebunch wheatgrass (*A. spicatum*) is slightly affected by burning. Twelve years after burning, Blaidell (1953) found an almost twofold increase in yield compared to unburned controls. After 30 years, yield of bluebunch wheatgrass on the same area was slightly below the controls (Harniss and Murray 1973). Cover of bluebunch wheatgrass remained uniform in west-central Utah for 40 years after burning before the juniper overstory caused a decline (Barney and Frischknecht 1974).

The negative effects of burning bluebunch wheatgrass are usually evident only in the first year after burning. Uresk and others (1976) measured decreases in leaf lengths and basal area, but an increase in yield 1 year after burning in eastern Washington. These results are similar to the 29 percent reduction in basal area and 1 percent mortality observed in the same region by Conrad and Poulton (1966). In eastern Oregon during mid-May, burning decreased the basal area by 78 percent with a 50 percent mortality. When plants were burned during the fall, there was no mortality but a reduction in basal area of 47 percent compared to preburn measurements of the same plants (Britton and Sneva 1977, personal communication). Effects of burning (Wright 1974) were magnified by an extremely dry year. Bluebunch wheatgrass will usually return to preburn production in 1 to 3 years (Blaisdell 1953; Moomaw 1957; Conrad and Poulton 1966; Uresk and others 1976; Daubenmire 1963, unpublished report).

Response of other wheatgrasses falls somewhere between crested wheatgrass and bluebunch wheatgrass with the exception of the rhizomatous wheatgrasses. Thickspike wheatgrass (*A. dasystachyum*) exhibits virtually no change 1 year after burning and after 12 years produces about twice as much as unburned controls (Blaisdell 1953). It appeared that the more intense the burn the greater the response. In northeastern California, a mixed wheatgrass stand was burned in the fall of the third growing season (Kay 1960). The following summer, a 25 percent increase in stocking was measured, primarily due to rhizomes of intermediate wheatgrass (*A. intermedium*) and pubescent wheatgrass (*A. trichophorum*). Tall wheatgrass (*A. elongatum*) remained unchanged. In North Dakota, western wheatgrass (*A. smithii*) was unchanged in frequency regardless of site or soil (Dix 1960).

Response of Forbs to Burning

Forbs generally respond better to burning than grasses. Where plant communities have large proportions of forbs in the herbaceous component, burning may provide the best manipulation technique. Fall burning does not harm most forbs because they are often dry and disintergrated by this time. Pechanec and Stewart (1944) classified forbs according to their susceptibility to fire.

Due to lack of research evidence on individual forb species, no attempt will be made to review each species mentioned in the literature. Instead, each article mentioning forbs will be abstracted.

Probably the best research treatment of forbs is from the prescribed burns conducted in Clark and Fremont Counties on the upper Snake River Plains of Idaho. This work is presented in a series of three articles by Pechanec and others (1954); Blaisdell (1953); and Harniss and Murray (1973). Pechanec and others (1954) observed that the rapidity of increase by the lightly damaged or undamaged species depended largely on whether the plant spreads by rootstocks. Those that do not, even though undamaged, increase slowly after burning. These include some of the more palatable species such as arrowleaf balsamroot (*Balsamorphiza sagittata*) and tailcup lupine (*Lupinus caudatus*). Despite a quick recovery from burning, any increase in number of plants must await seed production.

Plant species spreading by rootstocks or root shoots are least harmed and spread most rapidly after burning. These species include western yarrow (*Achillea lanulosa*), purpledaisy fleabane (*Erigeron corymbosus*), longleaf phlox (*Phlox longifolia*), flax-leaf plainsmustard (*Sisymbrium linifolium*), lambstongue groundsel (*Senecio integerrimus*), orange arnica (*Arnica fulgens*), and common comandra (*Comandra umbellata*). Such species as western yarrow, longleaf phlox, and purpledaisy fleabane doubled in production within 3 to 4 years.

Approximately 12 years after the burns in Clark and Fremont Counties, Blaisdell (1953) reevaluated the vegetation response. In Fremont County, he found total forb production was considerably higher on all burn intensities as compared to unburned areas. Forb production in pounds per acre was unburned, 127; light burn, 191; moderate burns, 237; and heavy burn, 170 (143, 215, 266, and 191 kg/ha). Of the species mainly responsible for the higher yield of forbs on burned areas, western yarrow, aster (*Aster* sp.), fleabane, and goldenrods (*Solidago* sp.) are rhizomatous perennials. Littleaf pussytoes (*Antennaria microphylla*), a suffrutescent forb of low forage value, and sticky geranium (*Geranium viscosissimum*), a perennial rated fair forage, also contributed to the higher yield, especially on light and moderate burns. On the other hand, yield of knotweed (*Polygonum douglasii*), an undesirable annual, was greatest on the heavy burn. The lower yield of plumeweed (*Cordylanthus ramosus*) on burned areas compared to unburned areas approached statisical significance.

The 1934 inventories showed a marked increase in total production of forbs on burned areas in relation to that on the unburned. This trend continued through the third year, especially on burns of light and moderate intensity. Although much of these early increases had disappeared by 1948, differences were still significant for light and moderate burns.

Rhizomatous species on all burn intensities showed relative increases the first year after burning, but subsequent trends were variable. On the other hand, suffrutescent forbs [pussytoes and eriogonum (*Eriogonum caespitosum* and *E. heracleoides*)], decreased markedly, roughly proportionate to burn intensity, and then increased. Annuals, primarily gayophytum (*Gayophytum diffusum*), knotweed, plumeweed, and goose-foot (*Chenopodium* sp.), made enormous relative increases in 1934, roughly in proportion to burn intensity. Portions of these relative increases persisted through 1936, but had disappeared by 1948 on all but the heavy burn. The persistence of annuals on the heavy burn was shown by actual yield of knotweed, 26 lb/acre (29 kg/ha) on the heavy burn as compared to 7 lb/acre (7.9 kg/ha) on the control. Other perennial forbs generally showed an initial but temporary increase after burning.

After 12 years, only the heavy burn in Clark County supported a significantly higher yield of forbs compared to the unburned area. It appeared that fleabane and phlox (both rhizomatous species) on burns of all intensities and lupines on the heavy burn were producing more than on the unburned ground. Apparently the effect of burning on the other forbs was negligible after 12 years.

In contrast with Fremont County, inventories of Clark County plots the year after burning showed a decrease in total forb production on burned areas in relation to the unburned. By the third year, considerable increases in relative yield were evident, but most of these early effects disappeared during the next 9 years. As in Fremont County, rhizomatous forbs generally increased the first year, but suffrutescent species, eriogonum and pussytoes, decreased markedly on all burns. Rhizomatous species continued to increase through the third year, then decreased. After the initial relative decreases, suffrutescent species increased throughout the study period and regained much of their original losses. With the exception of plumeweed, annuals were present only in very small amounts. Other perennial forbs increased the first year on burns of all intensities, but trends in following years were not well defined.

By 1966, Harniss and Murray (1973) found little difference in forb production on burned and unburned plots. Although individual species were not mentioned, perennial forbs accounted for the bulk of the production.

Abandoned fields on the Snake River Plains dominated by cheatgrass were burned during the early 1930's (Piemeisel 1938). The first year after burning the major portion of the vegetation was tumblemustard and Russian thistle, with some flixweed tansymustard (*Descurainia sophia*). It took 2 to 3 years for the fields to again be dominated by cheatgrass. Near Dubois, Idaho, Mueggler and Blaisdell (1958) reported an increase in forb production after burning. Those species most benefited included timber poisonvetch (*Astragalus convallarius*), purpledaisy fleabane, and lupine. Forbs that were injured include littleleaf pussytoes and matroot penstemon (*Penstemon radicosus*).

In western North Dakota, Dix (1960) found that wild lettuce (*Lactuca pulchella*) decreased about 20 percent. The most dramatic decrease (63 percent) was on loamy fine sand. Red globemallow (*Sphaeralcea coccinea*) increased when present in the vegetation.

Robocker and others (1965) found that burning decreased most forbs on a sandy soil in eastern Washington. Burning appeared to have reduced stands of tumblemustard, tansy-mustard (*Descurainia pinnata*), and whitlow-wart (*Draba verna*).

In west-central Utah, Barney and Frischknecht (1974) sampled burns ranging in age from 3 to more than 100 years. The most abundant forbs during the first stages of succession were pale alyssum (*Alyssum alyssoides*), flixweed tansymustard, sunflower (*Helianthus annuus*) coyote tobacco (*Nicotiana attenuata*), and Russian thistle. Because these forbs were abundant on recent burns, it can be assumed that they were not seriously damaged by burning.

Yarrow was found to decrease the first 2 years after burning in northeastern California (Countryman and Cornelius 1957). However, by the fifth year there was a 7.5-fold increase in crown area.

In eastern Oregon, tailcup lupine changed slightly in cover from an average of 15 percent to more than 16 percent 1 year after fall burning (Britton and Sneva 1977, personal communication). The burns were in a dry year followed by a drier year. Hammersmark (1977, personal communication) observed in southern Oregon that astragalus, arrowleaf balsamroot, tapertip hawksbeard (*Crepis acuminata*), tailcup lupine, globe-mallow, and foothill deathcamas (*Zigadenus paniculatus*) were not damaged by wildfire. In Nevada, Wagner (1977, personal communication) measured a three-fold increase in frequency of longleaf phlox with no reduction in wild onion, astragalus, tapertip hawksbeard, lupines, globemallow, and foothill deathcamas as a result of wildfire.

Response of Shrubs to Burning

Bitterbrush

The specific effect of fire on bitterbrush depends on the species and location (Nord 1965). For example, abundant resprouting of antelope bitterbrush (*Purshia tridentata*) occurs in eastern Idaho (Blaisdell 1953; Blaisdell and Mueggler 1956), limited resprouting occurs in central and northern Utah (Blaisdell and Mueggler 1956), and very little resprouting occurs in Oregon and California (Nord 1965). Billings (1952) reports that fire eradicates bitterbrush in the western Great Basin because it rarely root-sprouts in that region, and seeds of bitterbrush do not disseminate from their source. Klebenow and others (1976) reported that in Nevada resprouts of bitterbrush generally died the year following burning. However, good production from seed resulted from the burn. The natural frequency of fire in areas that contain antelope bitterbrush is probably not more than 41 to 50 years, if that often.

Generally speaking, antelope bitterbrush is a weak sprouter and living plants are severely damaged by fire (Blaisdell 1953; Pechanec and others 1954; Countryman and Cornelius 1957; Nord 1965). For antelope bitterbrush to resprout regularly in areas such as southeastern Idaho, the soil must be wet at the time of the burn or shortly after the burn (Blaisdell 1953; Blaisdell and Mueggler 1956; Nord 1965). Otherwise, antelope bitterbrush seldom resprouts. If antelope bitterbrush plants do resprout, they will regain their original growth in 9 to 10 years (Blaisdell 1953). For a burn in Idaho that was followed by several dry years, antelope bitterbrush was only producing 50 to 60 percent as much as the control 12 years after the burn (Blaisdell 1953). The ability to resprout after pruning increases as the size and age of the plant increases (Ferguson and Basile 1966; Ferguson 1968; Ferguson 1972).

Ecotypic variation would normally be expected within a wide-ranging species like bitterbrush. Ecotypes of antelope bitterbrush have been observed. Alderfer (1977) reports three ecotypes in northern California and Oregon, a high elevation decumbent form, and two columnar forms. Monsen (1977, personal communications) has indicated three types occurring in Idaho, a low elevation decumbent form and two columnar forms, with one on granitic soils and the other on calcareous soils. In Utah, Plummer suggests that the decumbent and columnar forms represent at least two types.

The decumbent ecotype generally resprouts after fire or top removal. It is an aggressive pioneer species capable of revegetating severely disturbed areas after planting (Monsen and Christensen 1975). The columnar form on granitic soils in Idaho will also generally resprout after fire or top removal, but resprouting seems to be dependent on fire intensity and soil moisture. The other ecotypes apparently are more severely damaged by fire.

The decumbent life form is easily established from seed and is successfully used for rangeland and logging road rehabilitation, particularly on well-drained, coarse-textured soils (Monsen and Christensen 1975). Because seeds must be cold treated and scarified (Young and Evans 1976b), the best time to burn for seed production is the fall (Monsen and Christensen 1975). Abundant natural regeneration from seed caches following fall burning has been reported by Klebenow and others (1976). Seedlings from the low growing forms of antelope bitterbrush appear more competitive than do the upright forms (Monsen and Christensen 1975), and germination is high (Holmgren 1954). However, seedlings cannot compete with annual grasses during the first growing season (Holmgren 1954).

Desert bitterbrush (*Purshia glandulosa*) usually resprouts after fire (Nord 1965). This species is closely related to antelope bitterbrush and the two interbreed (Monsen and Christensen 1975) when their populations overlap. The amount of genetic variation induced by interbreeding significantly affects both palatability and resprouting in antelope bitterbrush.

Tentative conclusions deduced from the data presented on antelope bitterbrush follow: (1) High-intensity wildfires during midsummer do the most damage to bitterbrush when the burning is followed by summer drought; under these conditions, most of the bitterbrush is killed. Cool spring burns in the decumbent ecotype(s) of bitterbrush result in low mortality and high resprouting; however, few seedlings establish in the burned area. Fall prescribed burns result in higher mortality than spring burns, but lower mortality than summer burns. If fall prescribed burns are conducted with favorable soil moisture conditions at the time of the burn or just after the burn, resprouting and layering occur in the decumbent ecotype. Reproduction from seed is highest following a fall burn. (2) Fire harms the columnar ecotypes more than it does the decumbent ecotypes. Cool fall fires are more important for the survival of antelope bitterbrush in the upright growth forms. (3) Fire harms bitterbrush more on fine-textured and calcareous soils than on coarse-textured and well-drained soils. Specific habitat and soils data are not available.

Cliffrose

Two varieties of cliffrose are recognized (*Cowania mexicana* var. *mexicana* and var. *stansburiana*). Apparently, Stansbury's cliffrose is a strong sprouter and an aggressive pioneer species, whereas the mexicana cliffrose is a weak sprouter and not so aggressive. Research on *Cowania mexicana* shows that it is generally killed by fire (Pechanec and others 1954; Vallentine 1971; Klebenow and others 1976). Like desert bitterbrush, cliffrose interbreeds with antelope bitterbrush (Nord 1965; Sanderson 1969).

Sagebrush

Big sagebrush (*Artemisia tridentata*) is easily killed by fire (Blaisdell 1953; Pechanec and others 1954; Ralphs and others 1976). Blaisdell (1953) reports that big sagebrush does not resprout in southeastern Idaho, and repeated burning can almost completely eliminate sagebrush from a site (Pickford 1932). However, without repeated fires, sagebrush will reoccupy the burned area via seeding. Sagebrush can begin to reoccupy an area during the first year after the burn. Working at Dubois, Idaho, Blaisdell (1953) found that sagebrush in burned areas (12 years after the burn) was 10 percent of that in unburned areas, but had reached unburned levels in 30 years (Harniss and Murray 1973). Some areas recover more quickly if seed and moisture are available after burning (Pechanec and others 1954; Johnson and Payne 1968).

Mountain big sagebrush (*A. tridentata* ssp. *vaseyana*) recovers more quickly than other subspecies of big sagebrush perhaps because it occupies mesic sites and growing conditions are more favorable for seed production and reestablishment (Hironaka 1977, personal communication). Winward and Tisdale (1977) indicated that mountain big sagebrush shows a stronger tendency to increase in plant density and foliage cover in stands where herbaceous vegetation is disturbed than basin big sagebrush (*A. tridentata* ssp. *tridentata*) or Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*). Basin big sagebrush normally occupies lowland plains and valleys on basic soils, whereas Wyoming big sagebrush occupies drier valley and foothill sites (Plummer 1977). Though seed production is variable, depending on soil moisture conditions, germination rates of all three subspecies of big sagebrush are high enough in all years to exclude seed germination as a limiting factor to reinvasion (Harniss and McDonough 1976).

High intensity wildfires leave few unburned plants and consume most seeds, which accounts for the variable establishment density of big sagebrush. Maximum spread of progeny from parent plants of big sagebrush is 42 ft (12.8 m) (Frischknecht 1962), so wind is evidently not a major factor in moving seed from adjacent unburned areas into burned areas. Normally, seeds of big sagebrush do not remain viable in the soil or litter for more than 3 to 5 years (Monsen 1977, personal communication).

Other important related species are the lower growing black sagebrush (*A. nova*), low sagebrush (*A. arbuscula*), silver sagebrush (*A. cana*), and threetip sagebrush (*A. tripartita*). Fires rarely occur in the black and low sagebrush types. These shrubs grow in areas of shallow and droughty soils where production of herbaceous plants is often inadequate to support a fire. Black and low sagebrush can reproduce by seed after a fire but do not resprout. Three-tip sagebrush is a weak sprouter and silver sagebrush is a vigorous sprouter.

Rabbitbrush

Rabbitbrush (*Chrysothamnus* sp.), a common genera in the sagebrush-grass region, is usually enhanced by fire (Cottam and Stewart 1940; Blaisdell 1953; Countryman and Cornelius 1957; Chadwick and Dalke 1965; Young and Evans 1974). An exception to this general response are two observations by Robertson and Cords (1957) for rubber rabbit-brush (*Chrysothamnus nauseosus*). This species showed no recovery 2 years after a burn on September 3, 1942, near Mono Lake, Calif., and after a burn on November 7, 1943, near McGill, Nevada. However, burning in the latter area was repeated on an unburned area the following year on the same date and 95 percent of the plants resprouted. Evidently, the intensity of the fire is important because most of the sprouting after fire is epicormic (stem sprouting), not basal or root sprouting (Monsen 1977, personal communication).

All varieties and subspecies of *Chrysothamnua viscidiflorus* resprout vigorously and reseed well on disturbed areas (Plummer 1977). Seeds will carry long distances and growth of seedlings is rapid.

For living plants that resprout, production is reduced for 1 to 3 years after burning, then it increases dramatically (Blaisdell 1953). On the U.S. Sheep Station near Dubois, Idaho, burning reduced production 59 percent the first year after burning (Blaisdell 1953). Three years after burning, production doubled and was tripled at the end of 12 years. Similarly, Chadwick and Dalke (1965) found that the cover of *C. viscidiflorus* had increased fourfold to ninefold on 8- to 18-year-old burns on sandy soils in northeastern Idaho. Production of *C. bloomeri* (*C. viscidiflorus*) doubled 5 years after a burn in northern California (Countryman and Cornelius 1957). In western Nevada Young and Evans (1974) found that green rabbitbrush (*C. viscidiflorus* var. *viscidiflorus*) continued to dominate burns and reestablish itself periodically for 15 years. Communities 40 to 50 years old were dominated by big sagebrush and contained reduced populations of green rabbitbrush.

Broom Snakeweed

Broom snakeweed (*Gutierrezia sarothrae*) is a weak-sprouting perennial that is severely damaged by fire (Pechanec and others 1954; Wright 1972). It may be completely removed from an area (Stanton 1974). New plants tend to invade open areas rapidly, and the highest frequencies of broom snakeweed are found on 22-year-old burns (Barney and Frischknecht 1974). Populations decline gradually for 50 years. On 100-year-old burns, populations are reduced to less than 10 percent (Barney and Frischknect 1974).

Horsebrush

Horsebrush (*Tetradymia canescens*) is a vigorous postfire sprouter that also reproduces abundantly from seed. Species of horsebrush cause liver damage to sheep, with symptoms of photosensitization developing into severe poisoning (Kingsbury 1964).

Fire may reduce horsebrush by 50 percent the first year after a burn, but the species doubles at the end of 3 years after a burn (Blaisdell 1953). Twelve years after this same burn, horsebrush had increased fivefold. Thirty years after the burn many plants became decadent and began to die out (Harniss and Murray 1973). If fire or chemicals are used to treat decadent growth, horsebrush will become overwhelmingly dominant.

In addition to spineless horsebrush (*Tetradymia canescens*), littleleaf horsebrush (*T. glabrata*) and catclaw or spiney horsebrush (*T. spinosa*) resprout after fire. However, littleleaf and catclaw horsebrush normally grow in drier sites in which there usually is not enough fuel to carry a fire (Hironaka 1977, personal communication). Hence, only spineless horsebrush is a potential problem following prescribed burning.

Gambel Oak

In Colorado, fire stimulates suckering of Gambel oak with a resultant thickening and merging of stands into continuous thickets (Brown 1958). In Utah, McKell (1950) found that Gambel oak grew rapidly the first two growing seasons (50 percent recovery) after burning, but it had only recovered 75 percent of its original cover in 18 years after the burn (Wright 1972). The number of shoots increased after the fire and then declined until they were equal on both burned and unburned areas 18 years after the burn (Wright 1972). Oak tends to thin out and retreat when protected from fire (Brown 1958).

Snowberry

After fire, common snowberry (*Symphoricarpos albus*) will resprout vigorously from both rhizomes and basal buds. Creeping snowberry (*S. mollis*) is found in more mesic habitats. It is a weak sprouter after fire because its rhizomes, which may develop in deep humus, are sometimes consumed or damaged in an intense fire (Stickney 1977, personal communication). Mountain snowberry (*S. oreophilus*) is found in drier habitats extending into sagebrush grass. It is a weak sprouter after fire. Pechanec and others (1954) and Blaisdell (1953) found that it decreased initially after burning although no further change was observed 12 years after burning.

Snowberry is capable of producing firebrand material. When snowberry is located near fire control lines, it should be red-flagged as spot-fire.

Mountain-mahogany

True mountain-mahogany (*Cercocarpus montanus*) is a vigorous sprouter after being burned (Erdman 1970; Vallentine 1971). It is also highly palatable and of major importance in the Western United States (Medin 1960).

Curlleaf mountain-mahogany (*C. ledifolius*) is a weak sprouter after being burned, but many of the resprouts die during the following two or three seasons (Monsen 1977, personal communication). Curlleaf is a slow-growing species, particularly as a seedling, but it can grow into a small tree (Dealy 1975). Few treelike curlleaf mountain-mahogany plants resprout after fire (Monsen 1977, personal communication).

Rose

Several members of the rose family respond similarly to fire. Throughout their ranges serviceberry (*Amelanchier alnifolia*), oceanspray (*Holodiscus discolor*), ninebark (*Physocarpus malvaceous*), bittercherry (*Prunus emarginata*), little-wild rose (*Rosa gymnocarpa*), woods rose (*Rosa woodsii*), and shiny-leaf spiraea (*Spiraea betulifolia*), resprout from a root crown. They resprout in habitats of subalpine fir (Lyon 1976), grand fir (Asherin 1973), cedar-hemlock (Mueggler 1965; Leege 1968), Douglas-fir (Lyon 1971), ponderosa pine (Daubenmire and Daubenmire 1968), oak-brush (McKell 1950),

and sagebrush (Neuenschwander 1977, personal communication). Vegetative reproduction following burning is the primary method of propagation. Reproduction from seed is rarely observed after a burn. When seedlings are observed in a burn, their rate of growth is slow compared to that of other species (Stickney 1977, personal communication).

Serviceberry

Serviceberry may be the most palatable browse species and the most fire sensitive within the rose family. At least two growth forms are recognized (Lonner 1972), with several varieties. The most drought-tolerant variety, western serviceberry (*Amelanchier alnifolia* var. *utahensis*), is damaged by fire but it resprouts (Wright 1972; Stanton 1974). The more mesic variety, common serviceberry (*A. alnifolia* var. *alnifolia*) also resprouts and is not severely harmed. Based on observations in southern Idaho and in Utah, no mortality following wildfires has been recorded for Utah serviceberry (Monsen 1977, personal communication). Apparently western serviceberry, which is a longlived species (Hemmer 1975), can remain suppressed in a closed stand of conifers or juniper for a long period of time. Canopy removal of the resident trees will stimulate resprouting (Lyon 1971; Asherin 1973).

Ceanothus

Most seeds of *Ceanothus* can withstand high external temperatures and maintain germination capabilities (Biswell 1974). Snowbrush (*C. velutinus*) and redstem ceanothus (*C. sanguineus*) seeds require heat scarification before they will germinate (Lyon 1976). In addition, they resprout after fire. Sprouting may be considered an adaptation to recurring fires (Biswell 1974) because of the rapid growth and recovery after fire. Thus, *Ceanothus* is well adapted to fire for two reasons: (1) many of the shrubs resprout after fire; and (2) seeds, which are produced at an early age, may lie dormant and viable in the duff and soil for extremely long periods of time, and are highly resistant to fire. Seedlings are usually abundant after fire.

When Leege (1968) compared spring burns to fall burns to rejuvenate redstem ceanothus, spring burns were found to produce fewer resprouts than fall burns, and few seedlings of redstem ceanothus were alive by the end of the second growing season after the burn. However, many seedlings of redstem ceanothus survived the fall burn. Leege's study findings, if applicable to other species of *Ceanothus*, may imply that spring burning could potentially harm the species that reproduce primarily by seed. Success in regeneration and rejuvenation of *Ceanothus* following spring burning is extremely variable, presumably, due to the variation in duff moisture and fire intensity. However, spring burns do not require the fire control effort of fall burns, therefore spring burns are more economical. Late summer or fall burns, however, do increase the numbers of young plants and resprouts.

Response of Pinyon and Juniper to Burning

Pinyon and Juniper

The effect of fire on pinyon and nonsprouting juniper trees depends largely upon the height of trees, herbaceous fuel, weather conditions, and season. In open pinyon-juniper stands with an understory of 700 to 1,000 lb/acre (786 to 1,123 kg/ha) of fine fuel, Jameson (1962) and Dwyer and Pieper (1967) found that pinyon and juniper were easily killed by spring fires if less than 4 ft (1.2 m) tall when air temperature was 70° to 74°F (21° to 23°C), relative humidity 20 to 40 percent, and windspeed was 10 to 20 mi/h (16 to 32 km/h). Lower air temperatures in January [49° to 54°F (9° to 13°C)], a relative humidity of 44 percent, and windspeed of 6 to 8 mi/h (10 to 13 km/h) caused a very spotty burn in which crown kill varied from 30 to 70 percent for trees 2 to 4 ft (0.6 to 1.2 m) tall, but 70 percent of the trees eventually died (Jameson 1962).

A wildfire in June, with an air temperature of 97°F (36°C), windspeed of 10 to 15 mi/h (16 to 24 km/h), and relative humidity 17 to 25 percent assured a 100 percent kill of all trees less than 4 ft (1.2 m) tall, but was no more effective on taller trees than when air temperatures were 70° to 74°F (21° to 23°C) (Jameson 1962).

Trees greater than 4 ft (1.2 m) tall in open pinyon-juniper stands are difficult to kill unless you have heavy accumulations of fine fuel beneath the trees. On the wildfire studied by Dwyer and Pieper (1967), only 24 percent of the pinyon and 13.5 percent of the juniper that exceeded 4 ft (1.2 m) tall died. Jameson (1962) found that most juniper over 4 ft (1.2 m) tall only had a 30 to 40 percent crown kill, unless tumbleweeds had accumulated at the base of the trees. Then 60 to 90 percent of the crowns were killed, particularly for trees 8 to 10 ft (2.4 to 3.0 m) tall. East of the pinyon-juniper zone in Texas, juniper trees up to 12 ft (3.7 m) tall were easily killed when fine fuel was 2,000 lb/acre (610 kg/ha) or higher (Wink and Wright 1973).

Trees in closed stands (no grass or shrubs in the understory) of pinyon-juniper are difficult to kill because fires will not spread readily (Arnold and others 1964; Blackburn and Bruner 1975). Dense stands [495 to 988 trees/acre (1,222 to 2,440 trees/ha)] in 14- to 18-inch (35- to 45-cm) rainfall areas with a mixture of pinyon and juniper can be burned on hot days, but pure stands of juniper are almost impossible to burn (Blackburn and Bruner 1975). A number of people in the Great Basin area speculate that it would require windspeeds exceeding 35 mi/h (56 km/h) to burn pure stands of juniper. Thus, many attempts to burn such stands have failed (Arnold and others 1964; Aro 1971). As the proportion of pinyon to juniper increases and the density increases, the stands are easier to burn (Truesdell 1969; Blackburn and Bruner 1975). Such areas are usually burned by clearing an area 20 to 125 ft (6.1 to 3.8 m) wide and pushing a windrow against the green trees on the windward side and letting the material cure for 60 to 90 days. Then in June or July, burns are conducted when temperatures vary from 80° to 95°F (27° to 35°C), relative humidity is 4 to 8 percent, and windspeeds exceed 8 mi/h (13 km/h) (Truesdell 1969; Blackburn and Bruner 1975). These burns have been conducted on mesas or next to the Grand Canyon where firebrands are not a problem.

A mixture of sagebrush and pinyon-juniper is common throughout the Great Basin, and it is feasible to burn and kill large pinyon and juniper trees in these communities (Bruner and Klebenow (1979). To get a fire to carry, Bruner and Klebenow (1979) have proposed the "White Pine County Formula" where,

Index = Maximum wind (mi/h) + Shrub and tree cover (%) + Air temperature (°F).

If the index is 110 or higher a fire will carry and will kill the large pinyon and juniper trees. If the index is above 130, it is too dangerous to burn. Most of the work by Bruner and Klebenow has been done in pinyon-juniper stands with 45 to 60 percent of shrub and tree cover and burned when air temperature was 60° to 75°F (16° to 24°C), relative humidity was below 25 percent, and maximum windspeed was 5 to 25 mi/h (8 to 40 km/h).

Alligator juniper and redberry juniper are the only sprouting junipers. Smith and others (1975) found that if the tops of redberry juniper trees were removed before they reached 12 years of age, 99 percent mortality could be expected. Older trees were not studied. This data implies that if burned every 10 years or so, sprouting species of juniper may have a difficult time invading grasslands. Schroeder (1956) found that about 40 percent of alligator juniper trees less than 15 ft (4.6 m) tall could be killed by burning individual plants.

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TABULAR SUMMARY — FIRE EFFECTS DATA FOR PLANT SPECIES

Table 2.--*Summary of fire effects on major grass and grasslike species*

Species	Response to fire	Recovery time	Remarks
		Years	
Bluegrass			The bluegrasses are generally small plants and fire damage is minimal with late summer and fall burns.
Big	Slight damage	1-3	
Cusick	Slight damage	1-3	
Nevada	Slight damage	1-3	
Sandberg	Undamaged	1-3	
Cheatgrass	Undamaged	1	Any reduction in cheatgrass stands is usually short-lived.
Idaho fescue	Slight to severe damage	2-30	Spring or fall burning with adequate soil moisture appears to damage plants only slightly, but this species can be seriously harmed by hot summer or fall fires, particularly where precipitation is marginal for the existence of this species.
Indian ricegrass	Slight damage	2-4	Good resistance to burning but slow to increase in density.
Junegrass	Undamaged	1-3	Probably increase in density for several years after burning.
Needlegrass			Needlegrasses are generally the least fire-resistant bunchgrasses. Large plants are damaged more than small plants. A 50 percent reduction in basal area should be anticipated among the various size plants in a given area.
Columbia	Moderate damage	3-5	
Needle-and-thread	Severe damage	4-8	
Thurber	Severe damage	4-8	
Western	Moderate damage	3-5	
Plains reedgrass	Undamaged	1-2	Rhizomatous species that is fire resistant.
Sedges			
Douglas	Undamaged	1-3	
Threadleaf	Severe damage	4-10	
Bottlebrush squirreltail	Slight damage	1-3	One of the most fire-resistant bunchgrasses, although burning in a dry year can reduce basal area. Bottlebrush squirreltail can increase several years after burning.
Wheatgrass			Bluebunch wheatgrass can be damaged if burned in a dry year. Other wheatgrasses are difficult to burn in seeded monocultures.
Bluebunch	Slight damage	1-3	
Crested	Undamaged	1-2	
Intermediate	Undamaged	1-2	
Pubescent	Undamaged	1-2	
Riparian	Undamaged	1-2	
Tall	Undamaged	1-2	
Thickspike	Undamaged	1-2	
Western	Undamaged	1-2	

Table 3.--*Response of cold desert forbs to fall burning*

Severely damaged	Slightly damaged	Undamaged
Hairy fleabane	Astragalus	Arrowleaf balsamroot
Hoary phlox	Matroot	Common comandra
Littleleaf pussytoes	Munro globemallow	Common sunflower
Low pussytoes	Northwestern paintbrush	Coyote tobacco
Mat eriogonum	Pinnate tansymustard	Douglas knotweed
Uinta sandwort	Plumeweed	Flaxleaf plainsmustard
Wyeth eriogonum	Red globemallow	Flixweed tansymustard
	Sticky geranium	Foothill deathcamas
	Tailcup lupine	Gayophytum
	Tapertip hawksbeard	Goldenrod
	Tongueleaf violet	Goosefoot
	Tumblemustard	Lambstongue groundsel
	Wavyleaf thistle	Longleaf phlox
	Whitlow-wart	Orange arnica
	Wild lettuce	Pale alyssum
		Purpledaisy fleabane
		Russian thistle
		Velvet lupine
		Western yarrow
		Wild onion

Table 4.--*Summary of fire effect on major shrub species in the drier forest and sagebrush grass zones of the Intermountain region*

Species	Sprouting ability	Response to fire	Recovery time	Remarks
			Years	
Antelope bitterbrush	Weak sprouter	Severely damaged by summer and fall burns	30-40	Effect determined by growth form; decumbent form sprouts vigorously, columnar form is a weak sprouter. If plants sprout, they will recover in 9 to 10 years. Spring burns enhance sprouting but fall burns are best for reproduction from seed. Burn when soil is wet.
Desert bitterbrush	Sprouter	Unharmed		
Cliffrose	Weak to nonsprouter	Usually killed by fire		
Big sagebrush	Nonsprouter	Severely harmed	30	Good seed crop before burning hastens recovery. Effective control requires burning before seed-set and periodic burns. May use black and low sage as fuel breaks. Subspecies of big-sagebrush appear to be important relative to response to burning.
Black-sagebrush	Nonsprouter	Rarely burned		
Low sagebrush	Nonsprouter	Rarely burned		
Silver sagebrush	Sprouter	Slightly harmed		
Three-tip sagebrush	Weak sprouter	Harmed	30	
Rubber rabbitbrush	Vigorous sprouter	Enhanced	20-25	May be killed if burned after heavy grazing or burned in early summer.
Green rabbitbrush	Vigorous sprouter	Enhanced	20-25	
Broom snakeweed	Weak sprouter	Severely harmed	20-25	Rapid recovery.
Horsebrush	Vigorous sprouter	Enhanced	30-35	Toxic, increases fivefold within 12 years.
Gambel oak	Vigorous sprouter	Enhanced	30-40	
Common snowberry	Vigorous sprouter	Unharmed	10	Enhanced by cool fires but harmed by hot fires.
Mountain snowberry	Sprouter	Slightly harmed	15	
Mountain-mahogany	Sprouter	Slightly harmed	Recovery times not available in literature.	More information is needed.
Western mahogany	Sprouter	Slightly harmed		
Curlleaf mahogany	Sprouter	Moderately harmed		
Serviceberry	Sprouter	Slightly harmed	30-50	Highly adapted to fire; soil being moist at the time of the burn is important. Usually poor reproduction from seed.
Ocean-spray	Sprouter	Enhanced	20-30	
Ninebark	Sprouter	Enhanced	20-30	
Bittercherry	Sprouter	Unharmed	30-40	
Rose	Sprouter	Enhanced	15-30	
Spireaea	Sprouter	Unharmed	20-30	
Ceanothus				
Nonsprouting group	Nonsprouters	Harmed by spring	Recovery times not available in literature.	Seedling are enhanced with fall burns.
Sprouting group	Vigorous sprouters	Unharmed to enhanced		

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field programs and research work units are maintained in:

- Billings, Montana
- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
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